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January 2003

Electronics and Electrical Engineering Laboratory

Electricity Division

Programs, Activities, and Accomplishments

THE ELECTRONICS AND ELECTRICAL ENGINEERING LABORATORY (EEEL)

One of NIST's seven measurement and standards laboratories, EEEL conducts research, provides measurement services, and helps set standards in support of the fundamental electronic technologies of semiconductors, magnetics, and superconductors; information and communications technologies, such as fiber optics, photonics, microwaves, electronic displays, electronics manufacturing supply chain collaboration; forensics and security measurement instrumentation; fundamental and practical physical standards and measurement services for electrical quantities; maintaining the quality and integrity of electrical power systems; and the development of nanoscale and microelectromechanical devices. EEEL provides support to law enforcement, corrections, and criminal justice agencies, including homeland security.

EEEL consists of six programmatic divisions and two matrix-managed offices:

Electricity Division

Semiconductor Electronics Division

Radio-Frequency Technology Division

Electromagnetic Technology Division

Optoelectronics Division

Magnetic Technology Division

Office of Microelectronic Programs

Office of Law Enforcement Standards

This publication describes the technical programs of the Electricity Division. Similar documents describing the other Divisions and Offices are available.
Contact NIST/EEEL, 100 Bureau Drive, MS 8100, Gaithersburg, MD 20899-8100, telephone 301-975-2220, http://www.eeel.nist.gov. These publications are updated biennially.

Cover caption: The Electricity Division actively supports a wide variety of customers, such as the electric power industry, users of flat panel displays, the electronic instrumentation and manufacturing industries, and all users of electrical measurements.

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U.S. DEPARTMENT OF COMMERCE
Donald L. Evans, Secretary

Technology Administration
Phillip J. Bond, Under Secretary of Commerce for Technology

National Institute of Standards and Technology
Arden L. Bement, Jr., Director

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Welcome

The **Electricity Division** maintains and disseminates the national standards of electrical measurement, such as the volt, ohm, farad, and watt. The Division also develops the measurement methods and services needed to support electrical materials, components, instruments, and systems used for the generation, transmission, and application of conducted electrical power. In addition, the Electricity Division performs related activities in support of the electronics industry, including research on video technology and electronic product data exchange.

Maintenance of the national electrical standards requires that the Division realize the electrical units in terms of the International System of Units (SI) at the highest levels of accuracy, assure consistency with other national realizations of the electrical units through international comparisons, and provide a sound measurement basis for fundamental electrical constants that are of importance to the scientific community.

The Division widely disseminates the results of its research, especially in the areas of advanced measurement technology and dissemination of national standards, through a variety of channels – for-fee calibrations, publications, software, conferences and workshops, and participation in standards organizations and consortia. NIST also actively seeks industrial, academic, and non-profit research partners to work collaboratively on projects of mutual benefit.

During the past year, the Electricity Division reorganized, combining the previous four groups into three. The reorganization, which was a result of the Division's 2001 strategic planning activity, increased the amount of Division resources directed at core metrology projects, improved team efforts, and minimized the number of administrative and management staff.

This book describes the research programs, activities, and recent accomplishments of the Electricity Division organized by research project. After the project descriptions is a list of the calibration services that the Division provides, NRC Postdoctoral Research opportunities within the Division, and finally an organization chart to facilitate contacting our staff members. For additional information about the Electricity Division, please visit our web site at http://www.eeel.nist.gov/811/.

Dr. James K. Olthoff
Chief, Electricity Division

Barry A. Bell
Deputy Chief, Electricity Division

Division Programs

The Electricity Division focuses on strengthening the U.S. economy by searching out, evaluating, and addressing needs that must be met to improve U.S. industry's ability to compete in the global marketplace. Our aim is to identify the needs that are of highest economic impact, that industry cannot effectively meet without the Division's help, and that the Division, with its technical expertise, can meet with deliverables appropriate to its mission. The Division serves the electronics, electrical-equipment, and electric power industries, government agencies, educational institutions, and through them all, the general public. These supported industries are pursuing sweeping changes including rapid exploitation of higher levels of technology, shorter product development cycles, increased product diversity, lower prices per function, and broader entry to mass commercial and consumer markets.

As part of the Electronics and Electrical Engineering Laboratory (EEEL), the Electricity Division conforms to the program structure used by the Laboratory to describe its programs. The six fields of technology that the Division's work impacts are: national electrical standards, low frequency, power, display metrology, electronic data exchange, and semiconductors.

National Electrical Standards

The availability of highly accurate, reliable, and robust measurement technologies is very important to research and development, manufacturing quality control, and marketplace exchange. Measurements of electrical quantities, such as the volt, farad, ohm and watt, are particularly important. In fact, electrical quantities are the common currency of measurements; that is, many non-electrical quantities are converted into electrical quantities to facilitate measurement by electronic instrumentation. Further, the foundational International System of Units (SI), and all research based on it, rely on a time-invariant, internationally consistent realization of the electrical units. The Division strives to improve the accuracy of these standards in response to ever-increasing needs by industry and research organizations for ever higher levels of performance. To achieve these goals, the Division has turned to quantum phenomena. They enable relating electrical quantities to unvarying fundamental atomic constants, such as the charge on an electron. Continued success in the implementation of electrical standards based on quantum phenomena could motivate a future redefinition of the SI to provide definitions more readily implemented by a broad range of users.

Low Frequency

Measuring derived electrical quantities linked to the SI units and national electrical standards is vital to supporting the vast array of "low frequency" electrical and electronic products available in today's marketplace. Such products include industrial electronics, consumer electronics, telecommunications equipment, computers, medical equipment, and automatic test systems. These products operate anywhere within a broad frequency range, extending from zero (direct current) up to tens of gigahertz. Although the Division does not have the resources to provide metrology support specifically targeted at each of these product areas, it does provide such support in fundamental forms that benefit them all. Typical measurement quantities of interest include AC voltage amplitude, AC current amplitude, impedance, dissipation factor, phase angle, AC ratio, power, linearity, total harmonic distortion, settling, delay/rise time, effective bits, signal-to-noise ratio, aberrations, 3 dB bandwidth, etc. Both manufacturers and users depend heavily on product accuracy for these derived quantities and need improved measurement methods as well as measurement linkages to standards maintained at NIST. Future work is focused on achieving higher accuracies at higher frequencies for evaluation of components, circuit assemblies, and equipment, and advancing measurement efficiency.

Power

The Division's support of electric power systems is driven principally by needs in the areas of energy efficiency, power quality measurements, and reliability. The U.S. consumes more than $240 billion of electricity annually. The fair, reliable, and efficient generation and delivery of this power is critical to U.S. industry and consumers, especially in light of the increasingly deregulated and fragmented areas of power generation, transmission, and distribution. The Division continues to develop improved measurement methods, supporting measurement reference standards, and calibration services to support revenue metering, equipment evaluation, and power quality. In an effort to preserve the reliability of power systems, suppliers are moving steadily toward more sophisticated control and monitoring technology. The Division is helping by providing measurement and security support for key monitoring devices.

Display Metrology

Television, computers, and telecommunications are merging into advanced digital video and computer systems that will provide new services for education, engineering, manufacturing, robotics, entertainment, medicine, defense, security, transportation, publishing, advertising, banking, and government. A critical element in this convergence is that electronic displays are becoming ubiquitous. Although displays are manufactured primarily offshore, U.S. manufacturers are the largest consumer of displays. To facilitate worldwide commerce in displays, a well-defined method for specification and verification of display quality is needed to ensure that the display will work under the necessary lighting conditions. NIST is working with industry standards-developing organizations to ensure such equity in the marketplace by developing the metrology base for displays.

Electronic Data Exchange

To implement new strategies for decreased time to market and reduced product design and manufacturing costs, manufacturers must implement strategies such as flexible manufacturing, collaborative development (internally and externally), concurrent engineering, and other advanced design and manufacturing techniques. These techniques are founded on the ability of manufacturers and suppliers to share information in computer-accessible digital formats. Three goals have been identified that are particularly relevant to the industries that the Division serves: 1) standardized data structures for describing product designs in a universal manner, 2) the standards needed to create an electronic marketplace that fosters collaborative efforts, and 3) standards to facilitate development of factory-automation software that is modularized in a standard manner to enable substitution of software modules from different vendors ("best-of-breed").

Semiconductors

Although the semiconductor industry is primarily served by the Semiconductor Electronics Division within EEEL, the Electricity Division with its expertise in fast pulse measurements, supports the semiconductor industry through research in precision measurements of jitter and time delay in microelectronic circuits. The Electricity Division has recently begun working with the semiconductor industry to develop standards for e-business.

Electricity Division Highlights

Improvement of High-Resistance Measurement Capability

Staff in the Electricity Division have developed a new technique that enables more accurate scaling from the primary NIST quantum Hall resistance standard to high resistance levels of 1 MΩ and above. The technique exploits a unique property of the quantum Hall effect, which allows a quantized Hall resistance standard to serve as a near-ideal two-terminal resistor whose resistance, 12906.4035 Ω, is essentially independent of the resistance of the room-temperature connecting leads. This will allow calibration of NIST 1 MΩ working standards with a relative uncertainty of better than 1×10^{-7}, an improvement of about an order of magnitude. The new measurement system was recently used to calibrate a set of four 1 MΩ resistance standards for an NCSL International interlaboratory comparison. The relative uncertainty for these calibrations is about 1×10^{-6}, a factor of three improvement over the present NIST calibration service.

Reduction in Uncertainties in Fast Pulse Calibration Service

The application of new test instruments, a new test procedure, and an improved uncertainty analysis has resulted in a significant reduction in the reported uncertainty for transition duration (i.e., rise time and fall times) provided by Special Test 65200S "Fast Repetitive Pulse Transition Parameters." The uncertainties have been reduced from -2.2 ps / +4.4 ps to ±1.5 ps. In addition, the parameters of overshoot and undershoot have been added to the list of parameters provided by the 65200S. The addition of these parameters was possible because of the new uncertainty analysis. The 65200S calibration service is used by manufacturers of high-speed samplers, military calibration laboratories, and aerospace and computer industries to calibrate the output of high-speed pulse generators and the step response of high-speed samplers. The reduction in transition duration uncertainty is significant because of the increase in speed of commercial samplers and in the circuits that they are intended to test. With these improvements there are no other national metrology laboratories that surpass the measurement capability of NIST in high-speed pulse parameters.

Flat Panel Display Specification Used by Army for Procurement of Displays

The Video Electronics Standards Association's (VESA) Flat Panel Display Measurements, Version 2.0 (FPDM2) document is being used by the US Army for procurement of flat panel display technology. FPDM2 was released in June 2001, and the Electricity Division Flat Panel Display Laboratory was responsible for 70 % of the document. Steve Kutner of Bradley Engineering specifically thanked the efforts of the Electricity Division's FPDL project: "I express my appreciation for the contribution of Dr. Edward F. Kelley throughout the development and review process. Ed's energy and enthusiasm for proper metrology was the foundation for the requirements and test methods. Without his guidance and counsel, the specification would have had major errors and would have been delayed significantly. I cannot overstate his contribution. It was exceptional by any standard. We looked at other standards (ISO, TCO, NIDL, etc.) but nothing came close to FPDM2's depth, coverage, and practicality."

Measurements Lead to Improvement in Zener Voltage Reference

Careful measurements made in the Electricity Division for the characterization of Zener voltage standards have enabled the manufacturer to redesign the instruments for improved behavior. As part of its efforts to develop a 10 Volt Measurement Assurance Program (MAP), the Electricity Division undertook an extensive study of the characteristics of eight Fluke 7001 Zener Voltage Standards under a wide range of differing environmental conditions. One striking feature of the measurements was that all units showed a strong correlation between the Zener voltage output and relative humidity. A retrofit to the product line was designed and implemented on four of the NIST units as a test. Subsequent measurements at NIST confirmed a large reduction in the sensitivity to humidity changes, greatly improving the potential for use of these devices as transfer standards for the NIST 10 V MAP. The availability from NIST of the crucial data and the active response from the manufacturer resulted in a significant improvement in the performance of these high precision voltage standards.

Consumer Power Quality Guide for NRECA Written

Electric power quality problems are often monitored by electric utilities through customer reporting: if the lights flicker or go out, the utility learns of the problem when customers affected by the problems call in to report them. The National Rural Electric Cooperative Association (NRECA) has just published a guide written by the Electricity Division aimed at helping the utility customer service representatives and customers communicate better and quickly identify the causes of their power problems. This 36-page manual, *Consumer Power Quality Problems: Troubleshooting by Telephone*, provides a summary of typical power quality disturbances and their effects on appliances, lights, and other electronics, with suggestions for possible remedies. A systematic classification of the types of appliances and the symptoms of the problems enables the customer service representatives of these sometimes-small electricity cooperatives to lead the affected customers through a series of questions that narrows down the possible causes and allows a tentative diagnosis to be formulated. The service representatives can then suggest possible solutions, resulting in a highly cost-effective telephone session. The guide is now being disseminated with great success among the member utilities of NRECA.

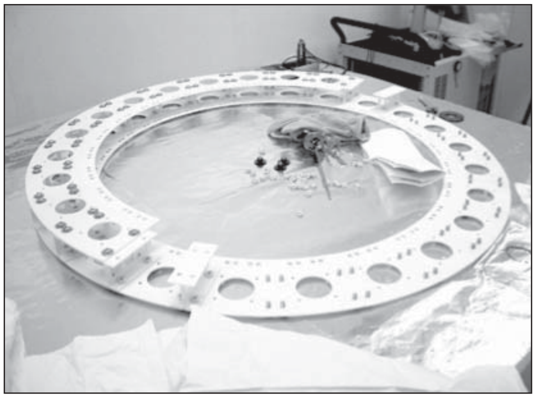
Researchers Two Steps Closer to Electron-Counting Capacitance Standard

The Electron-Counting Capacitance Standard (ECCS) is being developed, in collaboration with the EEEL Electromagnetic Technology Division in Boulder, as a quantum-based representation of capacitance. It relies on pumping a precisely counted number of electrons (about 100 million) onto the plates of a cryogenic capacitor and measuring the resultant charging voltage. A team of scientists in the Electricity Division made two advances in the development of cryogenic capacitors for use with the ECCS. First, physical design changes have improved its stability and allowed an increase of its nominal value by an order of magnitude, to 10 pF. The new device exhibits a capacitance drift of less than about 10^{-9} per hour. The second advance was the performance of a preliminary measurement of the cryogenic capacitor directly against the NIST calculable capacitor, the nation's fundamental standard for capacitance. Measurement against the calculable capacitor is crucial for the ECCS, both in terms of demonstrating its usefulness as a capacitance representation, and for the measurement of the fine-structure constant.

The Electronic Kilogram

Goals

To realize the electrical unit of voltage and to provide an alternative definition of the unit of mass that is based on measured quantities determined by fundamental physical constants of nature.



New ceramic coil form designed to reduce vibration-induced flexure of the moving induction coil.

Customer Needs

The kilogram is the only remaining base unit in the International System of Units (SI) whose definition is based on a physical artifact rather than on fundamental properties of nature. Environmental contamination or material loss from surface cleaning, or other unknown mechanisms, are causing the mass of the kilogram to vary by about 3 parts in 10^8 per century relative to sister prototypes. This observed drift highlights a significant shortcoming of the SI system. The measured values of many physical constants are based on mass, and these constants are regularly used in quantum-based measurement systems, such as the Josephson effect, which are becoming more significant to the growth of international technology and trade accreditation. Thus, with a time-drifting mass standard, adjustments to the value of physical constants must be made periodically to maintain the consistency of the SI system. Moreover, each future change will adversely affect a continuously growing technology base that relies increasingly on electronic testing, quality control, and environmental monitoring. The adoption of the electronic kilogram as the mass standard will improve the consistency of the SI and will also provide better determinations of many fundamental physical constants, such as the charge and mass of the electron, that serve the general scientific and technological communities.

Technical Strategy

The equivalence of electrical and mechanical power provides a convenient route to the measurement of mass in terms of other quantum mechanically defined measurement units. The apparatus at the Electronic Kilogram facility is a balance that compares both kinds of power in a virtual measurement that is unaffected by the dissipative forces of friction and electromagnetic heating. The experimental observables are length, time, voltage, and resistance. These quantities are all measured with respect to fundamental and invariant quantum phenomena: atomic clocks, lasers, the Josephson effect, and the quantum Hall effect.

It is necessary to reduce the total measurement uncertainty of this experimental apparatus by a factor of 10 to the level of 0.01 parts per million (ppm) to monitor the mass of the kilogram artifact mass standard. A substantial upgrade of the facility to reduce many known sources of error has been accomplished to achieve this goal. Experimental operations this year included extended tests at full magnetic field and combined-mode watt data acquisition in vacuum. At years end, a new induction coil was being wound. With an ultra-stiff ceramic form, this coil should reduce ground vibration effects. Also, several custom-built electronic current sources and pre-amps were being tested for use in producing a quieter, more stable magnetic field and higher resolution voltage measurement.

DELIVERABLES: By 2003, establish the performance level of the full system with respect to long-term stability of alignment, data acquisition, and reference standards, and determine the uncertainty achievable for the watt realization.

DELIVERABLES: By 2004, optimize the system for regular monitoring of the kilogram at an uncertainty level of 0.01 ppm.

Related to this work is a multi-lab effort to provide the measurement of micro-scale forces that are traceable to the International System of Units (SI). The accurate realization and measurement of micro- and nano-Newton level forces requires the development of a new kind of force comparator housed in an appropriate laboratory environment with vibration isolation, climate control, and low airborne contaminant levels. This five-year competence project, the Microforce Realization and Measurements Project (MFMP), includes researchers from the Automated Production Technology

Technical Contact:
Richard L. Steiner

Staff-Years:
3.0 Professionals
0.5 Postdoc
1.5 Guest Researchers
0.5 Students

and Precision Engineering Divisions of the Manufacturing Engineering Laboratory (MEL), from the Ceramics Division of the Material Science and Engineering Laboratory (MSEL), and from the Electricity Division.

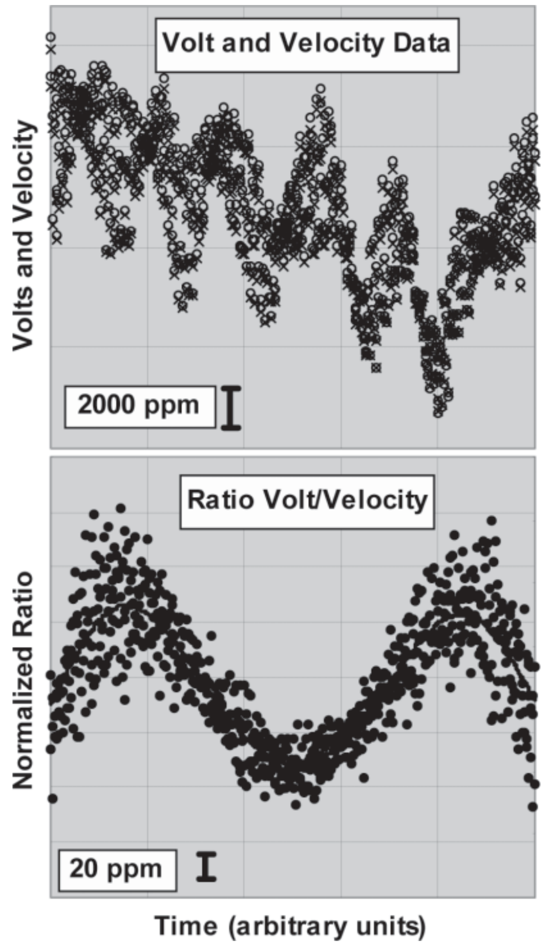
DELIVERABLES: By 2003, complete the development of the preliminary electromechanical force balance and demonstrate the comparison of mechanical to electrical forces at a level of 10^{-5} N with a total relative uncertainty of 10^{-3}.

DELIVERABLES: By 2005, establish a metrological basis for small force measurement by developing an electronic realization of force traceable to the SI in the regime between 10^{-8} N and 10^{-4} N.

Accomplishments

- The watt balance system became fully operational using both volt/velocity and force/current modes. A new induction coil was installed and tested in air for about four months of shakedown operation at full magnetic field. This second induction coil was redesigned to be stiffer and equipped with the interferometer mirrors in optimal positions to reduce the effect of internal vibrations producing uncorrelated voltage pickup. Results indicated an improvement of 10 times less noise at vibration frequencies near 20 Hz. However, reinforcing fiber, epoxy, and a conductive coating meant to help in the coil's stiffness and antistatic buildup inadvertently caused severe leakage resistance. A new coil form composed of interlocking ceramic pieces was designed to address these problems and further increase the stiffness. It will replace the existing coil by December 2002.

- The in-air testing was followed by six weeks of testing in vacuum. All reference values were available for data analysis, including a programmable Josephson array and a GPS receiver. The measurements demonstrate that the average value of the daily data runs was very stable; the standard deviation of the runs generally ranged from 0.2 ppm to 0.4 ppm, uncorrected for tides. While not yet an improvement over the measurements routinely achieved leading up to the 1998 results, many control parameters have not yet been optimized. Because there are known sources of error at present (e.g., serious leakage resistance in pickup-coil, small instabilities of the magnetic field, and some remaining issues with the data analysis algorithms) it is too early to make any comparison of the present measurements with the previously reported realization of the watt. Some new electronics for reducing the noise in the magnetic field control are now ready for on-line testing, and recent programming optimization has reduced the signal/noise ratio in the volt/velocity ratio measurement.



The upper curves show the voltage (o) *and velocity* (×) *during a single sweep (≈75 duration) of the moving coil through the radial magnetic field. The relatively large scatter results primarily from relative differential vibration between the coil and the field. The lower curve shows the volt/velocity ratio, which should be nominally constant. Because the vibrations are common to both volt and velocity measurements, the scatter in the ratio is reduced by about 2 orders of magnitude. The ratio shows the typical "M"-shaped profile of the magnetic field.*

- Some long term testing has given reassurance that the alignments of the superconductor, coil, and laser optics are stable and reproducible. This was accomplished in part by improving the laser detection scheme for alignment positioning and also the room temperature control. By inserting the alignment system's diode laser beam into fiber optic cable, the number of guiding elements was reduced to one rigidly held launch fixture directly at the beginning of the reflector path. This eliminated the physical drift of multi-element mirror guides. Also, the building temperature controller was rebuilt and reprogrammed, now maintaining excellent thermal stability inside the balance room. This computerized measurement and feedback system overrides measurement and feedback of the pre-existing thermo-couple/pneumatic system to obtain long-term temperature control well within 0.2 C.

- For the Microforce Realization and Measurements Project, a preliminary microforce balance calibration system was completed this year, with results reported in a paper submitted at the Conference for Precision Electromagnetic Measurements 2002 in Ottawa Canada. Measurement tests at 10 μN, 100 μN, and 200 μN resulted in discrepancies between mechanical and electrical components at parts in 10^4 with uncertainties of similar value. This system was used to calibrate a commercial piezo-resistive force cantilever to an uncertainty of about 2 %. This result is several times better than the 10 % specification of the instrument.

FY Outputs

Collaborations

Edwin Williams and David Newell are collaborating with the Automated Production Technology, Precision Engineering, and Ceramics Divisions at NIST in a competence project for Microforce Realization and Measurement.

Recent Publications

R. L. Steiner, D. B. Newell, E. R. Williams, and R. Liu "Status of the NIST Electronic Kilogram Experiment," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2002), 16-21 Jun 2002, Ottawa, Canada, pp. 578-9. (Jun 2002).

D. B. Newell, J. R. Pratt, J. A. Kramer, D. T. Smith, and E. R. Williams, "The NIST Microforce Realization and Measurement Project," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2002), 16-21 Jun 2002, Ottawa, Canada, pp. 520-1. (Jun 2002).

J. P. Schwarz, R. Liu, D. B. Newell, R. L. Steiner, E. R. Williams, D. Smith, A. Erdemir, J. Woodford, "Hysteresis and Related Error Mechanisms in the NIST Watt Balance Experiment," J. Res. Natl. Inst. Stand. and Technol. (U.S.), 106 (2), 381-389 (2001).

D. B. Newell, J. R. Pratt, J. A. Kramar, D. T. Smith, L. A. Feeney, and E. R. Williams, "SI Traceability of Force at the Nanonewton Level," Proc. Natl. Conf. of Standards Laboratories (NCSL) Intl. 2001 Workshop and Symp., Jul 29-Aug 2, 2001, Washington, DC (Jul 2001).

M. H. Kelley, "The Electronic Kilogram," 2001 IEEE MTT-S Intl. Microwave Symposium Digest, May 20-25, 2001, Phoenix, AZ, pp. 857-860 (May 2001).

J. R. Pratt, D. B. Newell, E. R. Williams, D. T. Smith, and J. A. Kramar, "Towards a Traceable Nanoscale Force Standard," Proc. 2nd Intl. Conf. European Soc. for Precision Engineering and Nanotechnology (EUSPEN)," May 27-31, 2001, Turin, Italy, pp. 470-473 (May 2001).

R. E. Elmquist, M. E. Cage, Y-h. Tang, A.-M. Jeffery, J. R. Kinard, Jr., R. F. Dziuba, N. M. Oldham, and E. R. Williams, "The Ampere and Electrical Standards," J. Res. Natl. Inst. Stand. Technol. (U.S.), 106, pp. 65-103 (Jan/Feb 2001).

Voltage Metrology

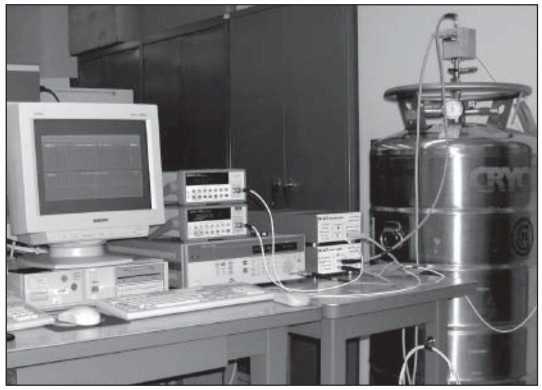
Goals

To maintain the U.S. legal volt and to provide for the dissemination of an internationally consistent, accurate, reproducible, and traceable voltage standard that is tied to the SI units and is readily and continuously available for the U.S. scientific and industrial base.

Compact/portable Josephson-array voltage standard (JVS) under development as transfer standard for high-level comparisons of laboratory JVS systems.

Customer Needs

All voltage measurements performed in the U.S., whether for the purpose of direct voltage reading or for the determination of another parameter (such as temperature) through the use of a transducer that converts that parameter into a voltage signal, rely for consistency on traceability to international standards through the U.S. legal volt. Because of the length of the calibration chain that connects measurements by an end user with the U.S. legal volt, it is common for the measurement uncertainty of the end user to exceed the NIST primary uncertainty by a factor of 100 or more. The continued development and deployment by the U.S. electronics instrumentation industry of increasingly sophisticated and accurate instrumentation places ever-increasing demands for higher accuracy voltage metrology both in calibration and testing laboratories and on production lines and factory floors. Consequently, NIST is continuously pressed to reduce measurement uncertainty at the beginning of this chain and to develop improved mechanisms for dissemination to the end user. Through maintenance, development, and dissemination of the U.S. legal volt, this project provides the robust base for voltage metrology that enables the U.S. electronics instrumentation industry to compete successfully in the global market.



Programmable JVS being evaluated for potential use in the routine calibration measurement systems.

Technical Strategy

A representation of the SI unit of voltage has been established via the Josephson effect, to maintain and disseminate the U.S. legal volt. The measurement systems required to measure and transfer that voltage to other electronic systems and to chemical or electronic standards have been developed. To continually achieve the lowest possible uncertainty, project members: 1) perform regular checks for subtle systematic errors in both the Josephson voltage standard systems and the subsequent transfer systems, 2) perform regular comparison checks between NIST systems, 3) maintain long-term observations of well-characterized check standards, and 4) periodically verify our consistency with the international community through very careful international comparisons. Research continues on the physical and statistical limitations of metrology equipment and protocols both presently in use and under development in order to support future technological advances.

There has been an increasing demand in recent years, by industrial users of Josephson voltage standards, for NIST to provide voltage calibrations with reduced uncertainty than is presently available through our standard volt calibration services. To provide that reduced uncertainty in the voltage dissemination we are developing a Measurement Assurance Program (MAP), based on 10 V Zener reference standards, which will reduce the uncertainty delivered to our customers by approximately a factor of 4.

DELIVERABLES: By 2003, complete the documentation of the Zener-based 10 V MAP and establish as a regular measurement service.

Technical Contact:
Yi-hua Tang

Staff-Years:
2.0 Professionals

In recent years, an increasing number of Josephson voltage standards have been deployed both around the world and throughout the U.S. It has proven very difficult to verify in the field the performance of voltage metrology systems based upon Josephson standards because the accuracy of these measurements is limited by the performance of the Zener voltage references used as transfer standards. Because the ultimate performance of Josephson voltage systems should be much better than can be verified using these standards, a traveling compact Josephson voltage standard (JVS) is being developed, in collaboration with Division 814 in Boulder, along with measurement protocols appropriate for its use in the comparison between Josephson voltage systems in geographically separated locations. The elimination of problems associated with traveling Zener standards will substantially reduce the uncertainty of Josephson voltage intercomparisons.

DELIVERABLES: By 2003, complete the assembly of the compact JVS system and evaluate its performance for both direct and indirect Josephson comparisons.

DELIVERABLES: By 2004, perform a series of comparisons with other national metrology institutes or with high-level industrial metrology laboratories.

The NIST voltage calibration service presently relies on banks of electrochemical cells for the daily workload of calibrating customer standards. While these cells are quiet and predictable voltage sources and therefore convenient to use as calibration standards, they are physical artifacts with built-in limitations in their use and in their deliverable uncertainty. In order to simplify the chain of transfers which links the calibration bench with the Josephson voltage standard, it would be very useful to incorporate the Josephson array standard more directly into the customer artifact calibration system. In collaboration with the NIST Electromagnetic Technology Division, project staff are investigating alternative means for the incorporation of a Josephson array system into the daily service.

DELIVERABLES: By 2003, establish the viability of the 1 V programmable JVS for routine use in the NIST voltage calibration laboratory.

Construction of the new Advanced Metrology Laboratory (AML) is progressing on or ahead of schedule. Early in 2004, the NIST voltage metrology laboratory is scheduled to move into the AML to take advantage of its superior control of environmental parameters such as temperature and humidity. In addition to the substantial improvement in laboratory conditions, this move presents a significant challenge if it is to be accomplished with no disruption in the measurement services. This will require the establishment in the AML of an interim measurement facility and validation that its performance is equivalent to that of the existing measurement laboratory. Once comparability is established, the measurement services can be migrated into the new facility.

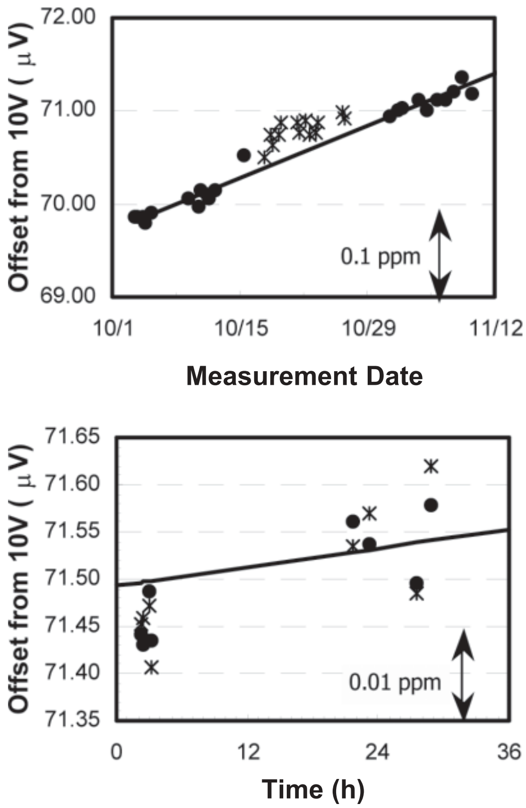
In addition to moving the measurement facilities into the new building, we will take this opportunity to modernize significant parts of the measurement hardware. Much of the existing instrumentation has begun to show its age and direct replacements are no longer commercially available. One challenge for the coming year is to evaluate potential replacements for critical parts of the measurement systems.

DELIVERABLES: By 2004, develop a detailed plan for establishing the interim measurement facility in the AML.

DELIVERABLES: By 2005, deliver voltage measurement services from the new facility in the AML.

Accomplishments

- An interlaboratory comparison was performed between the 10 V JVS-based measurement systems at NIST and Sandia National Laboratories (SNL). The technique used for this comparison resulted in a reduction by about an order of magnitude in the total uncertainty of this comparison compared with more traditional approaches. Rather than using electrochemical cells or Zener voltage references as the transfer standard, as has been the case for prior such intercomparisons, this comparison exploited the characteristics of a portable JVS system for the voltage transfer and hence provided a far superior overall accuracy for the comparison. The portable JVS, being based on the same fundamental physical principles as more typical laboratory JVS systems, allows transport of the voltage unit between laboratories with essentially the same accuracy as can be maintained at a national metrology institute such as NIST. Although direct comparisons between the portable JVS and the laboratory systems at NIST and Sandia could have been made in each laboratory, we chose to perform an indirect comparison, relying on near-simultaneous measurements of an intermediate Zener reference standard. Though this introduced some error due to the short-term noise of the Zener standard, it provided the significant benefit of providing a thorough verification of the full systems, including all system components, such as switches, DVMs and software, as used for the routine measurement workload. We achieved a total uncertainty of 1.9×10^{-9} (95 % confidence), representing a factor of 13 reduction in uncertainty compared to that achieved using a conventional Zener-based MAP procedure. This improvement is largely due to the elimination of uncertainty associated with the environmental and transportability effects of Zener standards. Work is in progress to establish a similar portable JVS in the voltage metrology laboratory at NIST.



Results of the JVS-based 10 V MAP demonstrating the improvement brought through use of a portable JVS as the transfer standard. The upper curve shows measurements by both NIST (•) and Sandia (×) on one of a set of four Zener voltage references during a conventional Zener-based MAP. The solid curve in the upper figure is a linear fit through the NIST measurements; this fit is extrapolated forward in the lower figure to the time of the JVS-based comparison. The lower figure shows measurements on the same Zener standard at Sandia using the portable JVS (•) and the laboratory JVS at Sandia (×). The JVS-based comparison delivers results with uncertainty reduced by more than an order of magnitude.

■ A programmable JVS (PJVS) system has been delivered by Division 814 and set up in the voltage calibration lab. Preliminary comparisons between the PJVS and the conventional Josephson voltage standard systems of 1 V and 10 V were performed. Differences at the 1 V level were found to be less than a few nanovolts. Unfortunately, the long-term stability and reliability of the programmable JVS is not yet adequate for incorporation into the routine measurement system. Efforts are presently underway in Division 814 in Boulder to address the stability issues.

■ In collaboration with Tom Witt of the BIPM, NIST undertook a study of correlation in high-precision measurements of Zener voltage references. Although modern Josephson-array voltage standards are capable of achieving relative uncertainties of 1×10^{-10} or better, nearly all voltage measurements, both in the U.S. and internationally, are traceable to this fundamental reference via transfer standards based on solid-state Zener voltage references. Even under the best laboratory environmental conditions, noise inherent to the solid-state references limits one's ability to measure their outputs to relative uncertainties of a few to many parts in 10^9. Through the application of advanced statistical analyses to the detailed noise measurements on many voltage references and the associated measurement instrumentation, we expect to develop more efficient protocols for high-precision measurements of laboratory standards.

■ Assistance was provided to National Institute of Metrology, Standardization and Industrial Quality (INMETRO), Brazil to establish proper operation at the 10 V level of its Josephson voltage standard (JVS). The system originally began operation in 1998 also with assistance from NIST, but only at the 1 V level. The upgrade to 10 V operation will greatly improve INMETRO's capability to maintain and disseminate the volt to industrial and scientific communities in Brazil.

FY Outputs

Calibrations

46 calibrations were performed with division income of approximately $57,000 received (October 1, 2001 to September 30, 2002).

Collaborations

Yi-hua Tang is working with Sam Benz, Charles Burroughs, and Paul Dresselhaus of the NIST Electromagnetic Technology Division to improve the long-term voltage stability of programmable JVS for applications of voltage dissemination. Yi-hua Tang collaborated with Thomas Witt of BIPM to study the correlation in electrical measurements and its applications in voltage metrology.

Yi-hua Tang collaborated with Fluke corporation to reduce the sensitivity of Zener voltage standards to environmental humidity.

Recent Publications

Y. Tang, S.L. Kupferman, and M.T. Salazar, "Interlaboratory Comparison Using a Transport Josephson Voltage Standard System," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2002), June 16-21, 2002, Ottawa, Canada, pp. 394-395 (June 2002).

C. Hamilton, Y. Tang, M.H. Kelley, S.L. Kupferman, D. Deaver, J. Ball, and B. Wood, NCSLI Recommended Intrinsic / Derived Standards Practice RISP-1 "Josephson Voltage Standard," 4th Edition (January 2002).

Y-h. Tang and J.E. Sims, "Complete Characterization of Zener Standards at 10 V for Measurement Assurance Program (MAP)," IEEE Trans. Instrum. Meas. Special Issue on Selected Papers CPEM 2000, 50, No. 2, pp. 263-266 (Apr 2001).

Y-h. Tang and W.B. Miller, "Interlaboratory Comparison of Josephson Voltage Standards Between NIST and Lockheed Martin Astronautics," IEEE Trans. Instrum. Meas. Special Issue on Selected Papers CPEM 2000, 50, No. 2, pp. 210-213 (Apr 2001).

D. Reymann, T.J. Witt, P. Vrabcek, Y-h. Tang, C.A. Hamilton, A.S. Katkov, B. Jeanneret, and O. Power, "Recent Developments in BIPM Voltage Standard Comparisons," IEEE Trans. Instrum. Meas. Special Issue on Selected Papers CPEM 2000, 50, No. 2, pp. 206-209 (Apr 2001).

R.E. Elmquist, M.E. Cage, Y-h. Tang, A.-M. Jeffery, J.R. Kinard, Jr., R.F. Dziuba, N.M. Oldham, and E.R. Williams, "The Ampere and Electrical Standards," J. Res. Natl. Inst. Stand. Technol. (U.S.), 106, pp. 65-103 (Jan/Feb 2001).

Y-h. Tang, J.E. Sims, and M.H. Kelley, "Future Voltage Metrology at NIST," Measurement Science Conference Proceedings, Jan 18-19, 2001, Anaheim, CA (Jan 2001).

Metrology of the Ohm

Technical Contact:
Randolph E. Elmquist

Staff-Years:
4.5 Professionals
1.0 Technician

Goals

To maintain the U.S. legal ohm and to provide for the dissemination of an internationally consistent, accurate, reproducible, scalable, and traceable resistance standard that is readily and continuously available for the U.S. scientific and industrial base.

Dean Jarrett works with the guarded-ring method measurement system.

Customer Needs

The U.S. electronics instrumentation industry, along with military and aerospace industries, maintains a position of world leadership through the development and deployment of increasingly sophisticated multi-function, high-precision and low-maintenance instruments. The ready availability of accurate and reliable precision electrical metrology is a critical need of continued instrumentation development. In addition, the U.S. electrical power industry relies on precise and accurate electrical metrology in both the distribution and metering of electrical power. To meet the present challenging needs and in anticipation of the increased demands of upcoming advanced instruments, this project is focused on the maintenance and dissemination of a reliable unit of resistance. Because reliable and stable resistance standards have been available for many years, many electrical measurements (e.g., at very high/low current levels) are converted to resistance measurements. Because of this very broad customer need, resistance dissemination is required to support a wide variety of impedance measurements, over a wide range of resistance levels, over a wide range of frequency, and at very high levels of accuracy. The activities of this project enable U.S. industry to demonstrate and verify in a cost-effective way the accuracy of electrical measurements and the performance of high-precision instrumentation in a competitive world environment.

Technical Strategy

Maintenance of the U.S. legal ohm requires research and the pursuit of scientific breakthroughs in quantum metrology to maintain a local representation of the unit, and requires close collaboration with other National Metrology Institutes, including participation in international metrology comparisons to ensure international consistency of electrical measurements.

There has in recent years been a marked improvement both in the capability of measurement laboratories to perform high resistance measurements and in the quality of available high resistance standards. The recently completed CCEM-K2 key comparison of high resistance standards clearly demonstrated this ability for National Metrology Institutes around the world. High resistance standards are also now commercially available with technical specifications that exceed, by as much as an order of magnitude, performance that can be verified with our routine services. This is particularly important given the severe demands placed on calibrations by the performance of newer generations of 8.5-digit digital multimeters.

Our present uncertainties for the calibration of high resistance standards are limited by the scaling measurements from the quantum Hall resistance (QHR) to the 1 MΩ level. Unlike the scaling down to 1 Ω and up to 10 kΩ, which presently rely on the Cryogenic Current Comparator (CCC) for direct scaling from the QHR and support relative uncertainties of about 1×10^{-7}, the scaling up to 1 MΩ starts at 10 kΩ and involves time-consuming and labor-intensive measurements using Hamon-type networks.

We will improve this scaling through the development of Cryogenic Current Comparator systems that will allow us to scale directly from the QHR to resistance levels of 1 MΩ and beyond. Thus far, we have demonstrated direct scaling to 1 MΩ using the CCC and SQUID as the only high-resolution detector, and using a special technique to eliminate effects of lead resistance. The measurement technique will be extended to resistance levels above 1 MΩ. In addition to its use in calibrations, this CCC system will be used for characterizing cryogenic resistance samples developed for the quantum metrology triangle experiment.

This improved scaling, along with other recent upgrades for the associated measurement systems, will allow us to reduce the uncertainty delivered to customers in many of our resistance measurement services.

DELIVERABLES: By 2003, construct a high-ratio CCC device for comparing the QHR to 100 MΩ, and characterize this CCC using resistance ratio networks and the QHR-to-1 MΩ CCC.

DELIVERABLES: By 2004, re-evaluate the uncertainty budgets for measurement services at resistances above 10 kΩ and deliver lower uncertainties that reflect the improvements resulting from the CCC scaling and other upgrades to the measurement systems.

The quantum metrology triangle is an experimental challenge that will test the fundamental concepts underlying the Josephson voltage standard, the QHR standard, and future current standards based on single-electron tunneling (SET) technologies. The ultimate success of this experiment awaits development of SET current sources capable of producing currents many orders of magnitude larger than is presently available.

Our work on scaling to high resistances, however, represents a initial practical step toward resistance measurements using quantum current sources built up from an SET pump. Along with our work to perfect high-ratio CCC scaling, we are pursuing the development of high-valued thin-film resistance standards. These standards, fabricated from CuSi alloys or other promising materials, are being produced using lithographic techniques both in Gaithersburg and Boulder.

We expect to develop standards with resistance of 100 MΩ or above and to use such a resistor to measure the small current of a single-electron pump.

DELIVERABLES: By 2003, fabricate and characterize thin-film resistance samples in the range 10 MΩ to 100 MΩ, and evaluate their performance for use in the metrology triangle experiment.

Construction of the new Advanced Metrology Laboratory (AML) is progressing on or ahead of schedule. Early in 2004, the NIST resistance metrology laboratories are scheduled to move into the AML to take advantage of its superior control of environmental parameters such as temperature and humidity. In addition to the substantial improvement in laboratory conditions, this move presents significant challenges if it is to be accomplished with no disruption in the measurement services. Our most heavily used calibration system, an automated guarded Kelvin bridge, is used for high-precision (0.15 ppm uncertainty) measurements of special air-type or oil-type high-quality 10 kΩ resistance standards. We are developing a plan to allow continuity of service for these and other calibration measurements while moving most of our calibration systems to the AML facility.

DELIVERABLES: By 2004, establish an interim calibration measurement system for 1 Ω Thomas-type and 10 kW special resistance standards to provide continuity of service during the move into the AML.

DELIVERABLES: By 2005, complete the establishment of resistance measurement services in the AML.

Accomplishments

■ We presented a paper at CPEM 2002 describing a new experiment based on the quantum metrology triangle, relating the Josephson effect (Josephson constant K_J) to the quantum Hall effect (von Klitzing constant R_K) and the precise control of SET pump electrical charge (e). This experiment could improve our knowledge of these constants, for example by passing a current $I_S = f_{SET}\, e$ through the quantized Hall resistance $R_H = R_K/i$ and comparing the resulting voltage to the Josephson voltage $V_J = n\, f_{JVS}/K_J$. Based on Ohm's law, this metrology triangle experiment would relate the ratio of the Josephson microwave frequency f_{JVS} and the SET pump cycle frequency f_{SET} to the dimensionless product,

$$e\, R_K K_J = \frac{a\, f_{JVS}}{f_{SET}} = 2 \; ,$$

where a represents a ratio of experimental integers, including the Josephson step number n, Hall plateau quantum number i, and number of electrons per pump cycle. From the 1998 CODATA recommended values of fundamental constants, measurements and theory that contribute to this combination of fundamental constants have a combined relative uncertainty of $u_r = 7.8 \times 10^{-8}$.

Our experiment would directly monitor a balance between two small, nearly equal currents. One current is induced by the voltage from a programmable JVS across a cryogenic resistor, and the other is generated by a SET pump device. The *difference current* is carried by a detector winding. We would measure this small current near the balance point using a SQUID sensor in a CCC configuration, and determine the critical frequency ratio (f_{SET} / f_{JVS}) that produces null indication. We have developed a cryogenic current comparator for calibrating the cryogenic resistor directly against the QHR. One benefit of this design is that it allows the SQUID to be the only low-noise detector in the experiment. We have characterized thin-film resistor samples made in Gaithersburg and Boulder, with cryogenic resistance values between 50 kΩ and 4 MΩ.

Cryogenic current comparator for measurement of 1 MΩ directly against the quantum Hall resistance.

- NIST has developed high-resistance standards and Hamon-type scaling networks for calibrations up to 100 TΩ, as well as an improved automated measurement system to replace manual high-resistance measurements. The development of a number of high-resistance standards was partially funded by contracts with DoD and DoE calibration laboratories. Characterized and calibrated hermetically-sealed Hamon-type high-resistance networks were prepared for Sandia National Laboratory. High-resistance calibration uncertainties have been re-evaluated and documented based on improved standards and automated measurement techniques.

- Some Rosa-type sealed 1 MΩ resistance standards have characteristic instability (nonlinear drift) and leakage resistance that reduces the accuracy of calibrations. The NIST Ring method system is not able to easily distinguish which of the resistors under test is unstable. Leakage in the resistors and unguarded Ring components contributes a systematic uncertainty, which is difficult to measure in the Ring system. We have used the new CCC bridge technique to characterize our Rosa standard resistors, used the results to improve scaling, and compared Rosa standards against newer 1 MΩ air-type resistance standards. This work supports a significantly reduced measurement uncertainty for a major U.S. inter-laboratory comparison at 1 MΩ in 2002-2003.

FY Outputs

Calibrations

313 calibrations were performed with approximately $306,000 income received (October 1, 2001 to September 30, 2002).

Recent Publications

R. E. Elmquist, N. M. Zimmerman, and W. H. Huber, "Using a High-value Resistor in Triangle Comparisons of Electrical Standards," to be published in IEEE Trans. Instrum. Meas. Special Issue on Selected Papers CPEM 2002.

D. G. Jarrett and R. F. Dziuba, "Report on CCEM-K2 Comparison of 10 MΩ and 1 GΩ Resistance Standards," to be published in IEEE Trans. Instrum. Meas. Special Issue on Selected Papers CPEM 2002.

N. F. Zhang, N. Sedransk, and D. G. Jarrett, "Statistical Uncertainty Analysis of CCEM-K2 Comparison of Resistance Standards," to be published in IEEE Trans. Instrum. Meas. Special Issue on Selected Papers CPEM 2002.

R. F. Dziuba and D. G. Jarrett, "CCEM-K2 Key Comparison of Resistance Standards at 10 MΩ and 1 GΩ ," Appendix B of Mutual Recognition Arrangement Bureau International des Poids et Mesures (BIPM) Report, also in Appendix B of the Bureau International des Poids et Mesures (BIPM) Key Comparison and Calibration Database http://www.bipm.org/pdf/final_reports/EM/K2/CCEMK2.pdf (also link from Metrologia, 2002, 39, Tech. Suppl., 01001).

D. G. Jarrett, "Analysis of a Dual-Balance High-Resistance Bridge at 10 TΩ," IEEE Trans. Instrum. Meas. Special Issue on Selected Papers CPEM 2000, 50, No. 2, pp. 249-254 (Apr 2001).

R. E. Elmquist, A.-M. Jeffery, and D. G. Jarrett, "Characterization of Four-Terminal-Pair Resistance Standards: A Comparison of Measurements and Theory," IEEE Trans. Instrum. Meas. Special Issue on Selected Papers CPEM 2000, 50, No. 2, pp. 267-271 (Apr 2001).

B. Schumacher, P. Warnecke, W. Poirier, I. Delgado, Z. Msimang, G. Boella, P. O. Hetland, R. E. Elmquist, J. Williams, D. Inglis, B. Jeckelmann, O. Gunnarsson, and A. Satrapinsky, Transport Behavior of Commercially Available 100-O Standard Resistors," IEEE Trans. Instrumen. Meas. Special Issue on Selected Papers CPEM 2000, 50, No. 2, pp. 242-244 (Apr 2001).

R. E. Elmquist, M. E. Cage, Y-h. Tang, A.-M. Jeffery, J. R. Kinard, Jr., R. F. Dziuba, N. M. Oldham, and E. R. Williams, "The Ampere and Electrical Standards," J. Res. Natl. Inst. Stand. Technol. (U.S.), 106, pp. 65-103 (Jan/Feb 2001).

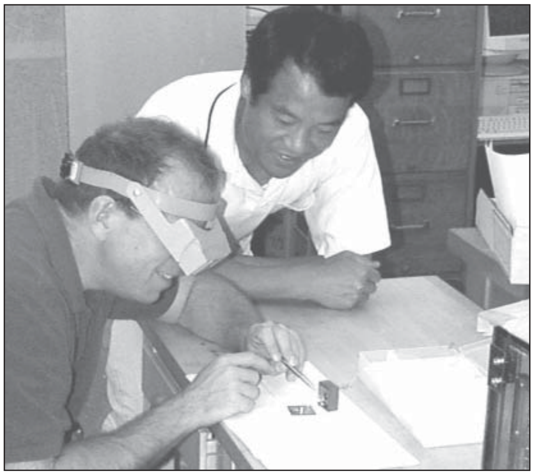
R. E. Elmquist, "What Metrology Gains With Quantized Resistance Standards," Proc. Metrologia 2000 Conference, Dec 4-7, 2000, Sao Paulo, Brazil, http://www.sbmetrologia.org.br/metrologia2000 (Dec 2000).

F. Delahay, T. J. Witt, R. E. Elmquist, and R. F. Dziuba, "Comparison of Quantum Hall Effect Resistance Standards of the NIST and the BIPM," Metrologia, 37, pp. 173-176 (2000).

Single Electron Tunneling

Goals

To develop applications of single-electron tunneling (SET) technologies that are relevant to high precision electrical metrology.



Neil Zimmerman and Yicheng Wang assemble vacuum-gap capacitor prior to cooling to 0.02 K, and testing.

Customer Needs

This project addresses three different needs: a fundamental representation of capacitance, a fundamental representation of electrical current, and general applications of SET devices, with a particular emphasis on future integrated nano-electronics.

The present representation of the SI farad is through silica-based artifact capacitors. Although these capacitors are of high quality, they are susceptible to drift in time and they may depend on other parameters such as temperature, pressure, and frequency. The metrology community, including both the national standards laboratories and domestic secondary calibration laboratories, needs a capacitance representation that is based on fundamental physical principles and not on properties of individual physical artifacts.

At present, there is no fundamental representation of current; the representation of current is via the representations of voltage and resistance. Though these representations are based on fundamental physical principles and are of high quality, the representation of current is dependent upon them. An independent representation of current could provide significant additional confidence in the coherency of the representations of the SI electrical units through closure of the "metrology triangle" $V = I R$ with all measurements based on fundamental constants.

Integrated circuit (IC) applications of SET effects are becoming more important, either deliberately, e.g., single-electron memory or quantum computing, or accidentally, as design rules continue to shrink. One very important practical problem with implementing SET-based device integration is the "charge offset" phenomenon. This phenomenon makes it difficult or impossible to integrate multiple SET-based devices together, thus engendering problems for the IC industry, which needs devices that are resistant to the charge offset.

Technical Strategy

This project is addressing these customer needs through the development of single-electron tunneling (SET) technologies. SET devices are being developed that will allow the reliable and reproducible control of individual electrons and hence will provide a standard of charge through control of these fundamental particles.

In collaboration with the Electromagnetic Technology Division of EEEL, SET devices are being used to develop an electron-counting capacitance standard (ECCS). By depositing a counted number, N, of electrons (of order 10^8) onto the plate of a capacitor (of value approximately 1 pF) and measuring the resulting voltage (approximately 1 V), one can calibrate the capacitance, C, through the definition of capacitance, $C = Q / V$, with the charge determined by the number of electrons, $Q = N e$.

To be useful as a capacitance standard, the capacitor used in this measurement must have rather special and very well characterized performance properties. A precision cryogenic vacuum-gap capacitor is being developed that is expected to meet the desired specifications of precisely tunable value, stability, frequency independence, etc. In addition, for purposes of calibrating other capacitance meters, we prefer a fairly large value.

To be useful as a standard, the performance of the integrated system must be thoroughly tested and characterized, it must be calibrated with respect to the SI farad, and all sources of systematic error evaluated, quantified, and understood.

DELIVERABLES: By 2004, perform detailed performance verification of the SET-based capacitance standard, determine its value relative to the calculable capacitor, and perform detailed uncertainty analysis of the integrated system.

Technical Contact:
Neil Zimmerman

Staff-Years:
1.0 Professional
0.5 Postdoc
0.5 Graduate Student

The ability to control electrons one-by-one in SET devices offers promise for several valuable new technologies. Possibilities include a current standard based on controlled pumping of single electron charges and the use of SET-based charge qubits as the building block to achieve quantum computing. At present, a primary difficulty with all applications of SET devices is that, because these devices are designed to control single-electron charges, they are extraordinarily sensitive to perturbations from tiny and uncontrolled sources of charge within a device; this charge offset is the biggest problem to be overcome and at present precludes convenient integration of multiple SET devices.

We have recently demonstrated that some Si-based SET transistors have a long-term charge offset drift that is about one thousand times smaller (better) than in metal-based devices. Unfortunately, the basic techniques used for the fabrication of these devices cannot readily be generalized to allow the fabrication of multi-junction devices suitable for use in more general devices such as the electron pump. We are investigating other fabrication techniques that offer potential solutions to our fabrication needs.

DELIVERABLES: By 2003, design, fabricate, and evaluate a simple, easy-to-fabricate, and more reliable Si-based SET transistor.

DELIVERABLES: By 2003, quantify and evaluate the differences in charge offset between metal-based and Si-based SET devices; suggest ways of improving the performance of the metal-based ones.

At present, a primary difficulty with the application of SET devices to fundamental electrical metrology is that a single device can supply a current of only 1 pA. This is too small by at least a factor of 100 for application in precision metrology. This project is pursuing approaches to integrate a large number of SET devices, so as to increase substantially the delivered current. However, this requires (in part) solving the charge offset, either intrinsically by virtue of device geometry or material, or by designing a charge offset-insensitive architecture.

DELIVERABLES: By 2004, produce a prototype device with parallel SET electron pumps.

DELIVERABLES: By 2006, produce a reliable SET current source with at least 100 pA of current.

One of the primary motivations for developing larger currents is our work to close the metrology triangle. This refers to a high-accuracy realization of Ohm’s Law, with each of the voltage, current and resistance being referenced to intrinsic quantum phenomena: voltage from Josephson-array voltage standards, resistance from quantum Hall resistance standards, and current from single-electron pumps. This experiment can not be performed with the currents presently available from single-electron pumps. However, even as we pursue the development of sufficiently high-current pumps for the direct closure of the metrology triangle, we are pursuing an alternate path to an indirect closure. In this experiment, an extension of the development of the ECCS, we close the triangle by measuring the voltage that develops on the plates of a capacitor as a result of the deposition of a countable number of electrons.

DELIVERABLES: By 2003, close metrology triangle to within 0.1 ppm via the charge-on-a-capacitor method.

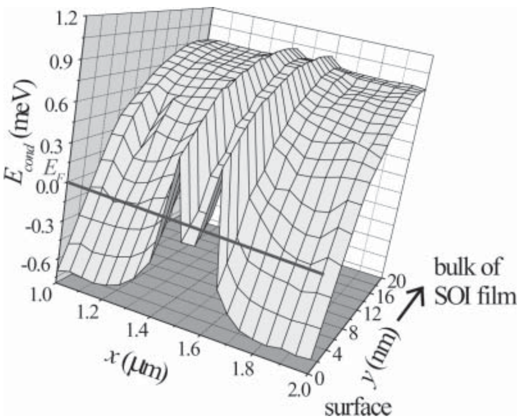
DELIVERABLES: By 2005, pursue individual elements, including larger-current SET-based current source, resistor, null detector, and control/monitoring electronics.

DELIVERABLES: By 2007, close metrology triangle to within 0.02 ppm via the current-through-a-resistor method.

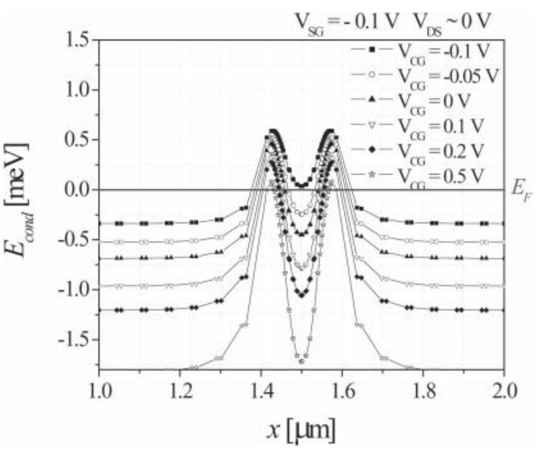
Accomplishments

- We have tested our new cryogenic vacuum-gap capacitors, which now have a value of 10 pF (previous value was 1 pF to 2 pF). We have demonstrated that they will satisfy many of the requirements of the ECCS, including, low drift at low temperatures, and low hysteresis upon thermal cycling. We have also succeeded in tying the value of the vacuum-gap capacitor to the SI unit of capacitance by measuring the value with respect to the calculable capacitor. This was accomplished by running the calculable capacitor in a novel mode to take advantage of its inherent tunability. We also measured the total uncertainty of this comparison, with a relative result of 3×10^{-8}.

- We have modeled and simulated our proposed Si-based SET structure, with good results. First, we obtained device parameters by simulating (using a commercial software package) a device fabricated by a different group, and verifying the simulation results as compared to the experimental data. In particular, we learned that the simulation results could not be taken as given: after the SET “island” carrier density has been turned on (gate voltage above threshold), its potential no longer changes. Secondly, we simulated our proposed structure, which eliminates the depletion gates previously used to form the tunnel junctions and thus simplifies the device and reduces the number of gates needed. We verified that tunnel barriers can still be formed naturally, as a result of the gaps between the inversion gates that form the islands.



Conduction band of simulated Si SET transistor with depletion gates.



Conduction band of proposed Si SET transistor without depletion gates; note that tunnel barriers still exist.

FY Outputs

Collaborations

Neil Zimmerman collaborates with Bruce Kane of the University of Maryland, and Marc Manheimer and Keith Schwab of the Laboratory for Physical Sciences (jointly operated by the University of Maryland and the National Security Agency) on SET fabrication, and on issues related to measurements and the charge offset problem in the context of quantum computing.

The Electron Counting Capacitance Standard is being developed in collaboration with Mark Keller and John Martinis of the EEEL Electromagnetic Technology Division.

Neil Zimmerman collaborates with researchers from the NTT Basic Research Laboratories in Japan for the characterization of Si-based SET devices, including pumps.

Neil Zimmerman collaborates with Eric Vogel, Curt Richter, and Jin-Won Park, all of the Semiconductor Electronics Division, on fabrication and characterization of basic Si-based SET devices.

Recent Publications

N.M. Zimmerman, M. El-Sabbagh, and Y. Wang "Improved Cryogenic Capacitor for the ECCS: Larger Value (10 pF) and SI Measurement by Tuning the Calculable Capacitor," to be published in IEEE Trans. Instrum. and Meas., Special Issue on Selected Papers CPEM 2002.

N.M. Zimmerman and W.H. Huber, "Excellent Charge Offset Stability in Si-based SET Transistors," Digest of Conf. of Prec. Electromag. Meas. (CPEM 2002), June 16-21, 2002, Ottawa, Canada, pp. 124-125 (June 2002).

M. El-Sabbagh, Y. Wang, N.M. Zimmerman, "A new, larger cryogenic capacitor, and a direct comparison to the calculable capacitor," Digest of Conf. of Prec. Electromag. Meas. (CPEM 2002), June 16-21, 2002, Ottawa, Canada, pp. 130-131 (June 2002).

R.E. Elmquist, N.M. Zimmerman, and W.H. Huber, "Using a high-value resistor in single-electron counting measurements," Digest of Conf. of Prec. Electromag. Meas. (CPEM 2002), June 16-21, 2002, Ottawa, Canada, pp. 324-325 (June 2002).

N.M. Zimmerman, W.H. Huber, A. Fujiwara, and Y. Takahashi, "Excellent Charge Offset Stability in a Si-Based Single-Electron Tunneling Transistor," Appl. Phys. Lett., 79, 3188 (2001).

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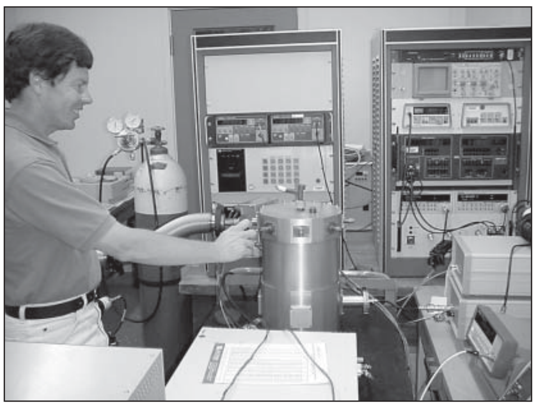
N.M. Zimmerman and M.W. Keller, "Dynamic Input Capacitance of Single-Electron Transistors and the Effect on Charge-Sensitive Electrometers," J. Appl. Phys., 87, No.12, pp. 8570-8574 (2000).

T.P. Moffat, J.E. Bonevich, W.H. Huber, A. Stanishevsky, D.R. Kelly, G.R. Stafford, and D. Josell, "Superconformal electrodeposition of Copper in 500-90 nm features," J. Electrochem. Soc., 147, No. 12, 4524-4535 (2000).

AC-DC Difference Standards and Measurement Techniques

Goals

To provide U.S. industry with the link between the DC and corresponding AC electrical standards, by maintaining and improving the U.S. national standards of AC-DC difference that are used to provide calibrations and measurement services for thermal converters and shunts.



Tom Lipe with the measurement system for testing cryogenic thermal transfer standards.

Customer Needs

Increasingly accurate, easier-to-use instruments and devices for precision AC voltage and current measurements are being developed by U.S. electronic instrumentation and test equipment manufacturers for use in a wide variety of industrial and scientific applications throughout the world. The need continues for better calibration tools with which to verify accuracy claims, achieve consistency, and to help avoid technical trade barriers. Research and development are needed to maintain and to expand NIST calibration and special test services for thermal converters and shunts, especially for calibrating high current shunts and high voltage converters. More reliable and easily fabricated thermal converter devices are needed. A new national primary standard is needed to support measurement uncertainties at the 0.1 µV/V level to support the electrical measurement industry. Several NIST customers who support the electric power industry require lower uncertainties at power frequencies at 120 V and 240 V.

Technical Strategy

Maintenance and development of primary standards and associated measurement systems used for NIST's world-class AC-DC difference capability requires the investigation and development of new or improved methods in thermal transfer technology. This capability is also needed for participation in international comparisons with other national metrology institutes to ensure international consistency.

AC current shunts are used in a variety of applications for current monitoring and limiting in transformers, motors and generators, bus bar switching, amplifiers, fusing, etc. In more exacting applications the value of such shunts must be accurately determined. Customer requests for an expanded parameter space (up to 100 kHz at 100 A) will be addressed by validation of the performance of the comparator systems and NIST AC-DC transfer shunts.

DELIVERABLES: By 2003, improve the NIST current shunt comparator system to provide calibrations up to 100 A and at frequencies above 10 kHz.

As the demand increases for a primary thermal transfer standard that can realize a zero AC-DC difference with an uncertainty (with k = 2) of < 0.1 µV/V, the need to identify promising new technologies for their design and fabrication becomes more critical. The thermal errors due to Peltier and Thompson effects in the heater structure of a thermal converter are temperature dependent and are among the larger error sources. NIST has proposed to minimize these errors by developing a cryogenic-based thermal transfer standard that can operate at 6 K. A prototype system has been constructed that shows promising results in significantly reducing thermal errors; additional unknown error sources have thus far prevented the successful development of primary standards based on this technology. An experiment has been designed to conclusively determine whether these errors are inherent to the cryogenic devices or whether they result from the cabling, packaging, or other interconnects. In this experiment, two cryogenic sensor chips will be mounted on a common header compared directly against each other in the cryostat, effectively eliminating from the comparison any effects not directly related to the cryogenic chips.

Technical Contact:
Thomas E. Lipe

Staff-Years:
2.0 Professionals
0.5 Technician

"[Tom Lipe] was extremely helpful … about the fine art of making good TVC measurements."

Larry Tarr, Chief
Electrical Standards Laboratory
US Army Primary Standards Laboratory

DELIVERABLES: By 2003, measure two cryogenic sensor chips against each other inside the cryostat at 6 K, and effectively determine the likelihood that this technology will provide a new primary standard.

DELIVERABLES: By 2005 (depending on the outcome of the preceding experiment), develop thermal transfer standards suitable for use as primary standards with performance characteristics superior to those presently in use.

Vacuum wire-type thermal converters have been established as the preferred thermal converter technology for several decades. In recent years, however, thin-film-type devices have been developed using semiconductor fabrication methods, and show promise for realizing lower manufacturing costs and improved performance. In collaboration with Sandia National Laboratories, NIST has designed and developed thin-film multi-junction thermal converters that are suitable for low voltages and currents. In response to requirements for measuring currents above 2 A, NIST is designing a module incorporating multiple thermal converters for use up to 20 A.

DELIVERABLES: By 2004, design, fabricate, and test a thin film multi-converter module suitable for currents of 20 A or more.

In order to measure higher voltages than are normally accommodated by thermal converters, a range resistor is placed in series with the heater element of the converter. However, the convenient means for bootstrapping the uncertainties achievable at lower voltage levels up to hundreds of volts involves additional measurement uncertainties due to heating in the range resistor and additional current leakage paths, which are also frequency dependent. Several national measurement institutes are developing different means for achieving better high-voltage AC-DC difference measurements. A comparator system using inductive voltage dividers has been constructed and tested at NIST. A simpler design, which promises improved performance, is in the planning stage. An amplifier capable of supplying the current required for the system at 1000 V and 20 kHz has been ordered.

DELIVERABLES: By 2004, develop a high voltage test set using binary inductive voltage dividers (BIVDs) to achieve an improved means for scaling up to 1000 V.

The electric power industry in the United States depends on NIST to provide the basis for the quantities of AC voltage and current. Recently, NIST customers that support this industry have requested uncertainties at power frequencies and voltages that are significantly smaller than the standard NIST uncertainties. NIST has already provided uncertainties of 6 μV/V to the NIST calibration service for power and energy. This uncertainty is reduced by more than a factor of two from that presently available for routine measurement services. The work that allowed delivery of this measurement result internal to NIST is an important first step leading to a reduction in the uncertainties provided to routine customers for AC-DC difference calibrations.

DELIVERABLES: By 2004, recharacterize the NIST reference and working standards of AC-DC difference in order to reduce the routine NIST uncertainty at 120 V and 240 V, 50 Hz and 60 Hz to 5 μV/V or less.

Thorough documentation is essential to maintaining an effective calibration service. The AC-DC Difference Project is revising the documentation describing the calibration service, the calculation of the uncertainties provided to its customers, and the technical documentation for its systems and software. When complete, the AC-DC difference laboratory will be in compliance with EEEL documentation requirements for calibration services.

DELIVERABLES: By 2003, acquire approval from the EEEL Measurement Committee for the documentation of the calibration service.

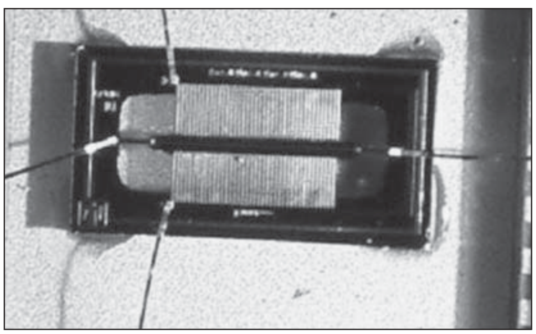
Accomplishments

- A new transition-edge sensor (TES) chip was fabricated by the EEEL Electromagnetic Technology Division in Boulder CO, and installed in the Cryogenic Thermal Transfer Standard cryostat in Gaithersburg. This new chip incorporates superconducting niobium ground planes for on-chip magnetic shielding to reduce the magnetic field coupling from the heaters to the TES to less than 1 % of that for the former TES chip. Experiments indicate that the AC-DC difference with 40 mV applied was reduced by about a factor of 5 and that the level coefficient from 40 mV to 20 mV at 1 kHz was reduced from +106 μV/V to +22 μV/V. As a current converter, the new chip has a level coefficient from 650 μA to 550 μA of about -10 μA/A at 1 kHz. These data confirm the prediction that the magnetic fields on the chip have been significantly reduced.

- Sandia National Laboratories delivered high-current thin-film multi-junction thermal converters (FMJTCs) with low-resistance gold heaters. AC-DC differences for four of the most closely matched FMJTCs were measured individually up to 100 kHz at 40 mA. These FMJTCs were then installed into a multiconverter-module capable of holding up to eight FMJTCs and measured at 200 mA. Individual chips showed AC-DC differences of less than

10 μA/A up to 50 kHz and less than 15 μA/A at 100 kHz. Measurements on the multi-converter module indicated AC-DC differences nearly identical to the individual chips at frequencies up to 20 kHz, with some deviation at higher frequencies. Although the performance of the multi-converter module is not completely predictable from measurements on individual devices, both the individual FMJTCs and the multi-converter module are suitable as working standards.

■ A new circuit design for the binary inductive voltage divider (BIVD)-based system for the characterization of high-voltage thermal voltage converters was developed. This new design requires the use of a very stable ballast resistor and a power amplifier capable of supplying the required current for the inductive divider. The specifications for the amplifier have been forwarded to Metrology Instruments, Inc. for construction. It is anticipated that the BIVD system will be operational at voltages up to 1 kV sometime in FY 2003.



Photograph of a thin-film multi-junction thermal converter showing the heater suspended on a thin membrane, the obelisk beneath the heater, and the web of thermocouples. To provide venting for the membrane, the chip is elevated from the packaging by the visible epoxy pads at the corners.

■ The uncertainty analysis of the AC-DC difference calibration service for voltage has been completed and is undergoing review. This document will form the basis for the uncertainty provided to our customers (internal and external), and presents the lower uncertainties now available. The operations manual for the NIST automated AC-DC calibration systems has also been approved for publication; it will also form part of the documentation for the AC-DC laboratory.

■ The NIST AC-DC Difference Laboratory participated in CCEM-K9, an international intercomparison of thermal converters at voltages of 250 V, 500 V, and 1000 V, from 1 kHz to 100 kHz. Previous measurements for this intercomparison in 2001 revealed problems with the stability of the measurements. It was found that the choice of digital voltmeter used to monitor the output of the thermal converters affected the AC-DC difference of the converters. When the traveling standards were measured using a nanovoltmeter with good common mode signal rejection, the measurements were consistent. The new values were reported to the pilot laboratory.

■ Work continues to extend the parameter space for current shunts to 100 kHz at 100 A. A current build-up from 20 A to 100 A at frequencies from 1 kHz to 100 kHz has begun, and the results of initial measurements are being evaluated. Formal expansion of the calibration service, however, awaits successful repair of critical instrumentation.

■ In an effort to reduce uncertainties for power calibrations provided to NIST customers, reduced uncertainties of 6 μV/V (instead of the usual 20 μV/V) were provided to the NIST digital voltmeter calibration laboratory as part of an internal calibration of a thermal transfer standard.

FY 02 Outputs

Calibrations

1089 calibration points for 29 customers at a cost of about $144,000 (October 2001 – September 2002).

Collaborations

Active collaborations continue with Carl Reintsema in the Electromagnetic Technology Division, NIST-Boulder, on the development of the cryogenic-based thermal transfer standard using resistive temperature edge sensor technology, and with Sam Benz, Charlie Burroughs, and Paul Dresselhaus in the development of an AC-based Josephson voltage standard.

The design, fabrication, and packaging of thin film, multi-junction thermal converter chips are being carried out in collaboration with Tom Wunsch at the Sandia National Laboratories.

Extensive collaboration continues with the U. S. Air Force Primary Standards Laboratory in Newark, OH, and with a manufacturer of AC current shunts being bought by the Air Force as high-current standards. The collaboration is working to help the Air Force establish broadband AC current measurement capability at 100 A.

Collaboration continues with Henry O. Wolcott of Metrology Instruments of Simi Valley, CA to develop improved high-voltage range resistors for thermal converters.

Collaboration continues with NRC in Canada and CENAM in Mexico to confirm the consistency of their AC-DC transfer standards with other NMIs.

External Recognition

Joseph Kinard and Thomas Lipe were co-recipients (with Thomas Wunsch of Sandia National Laboratories) of the Algie Lance Best Paper Award, given at the 2001 Measurement Science Conference for the paper "Recent Advances in AC-DC Transfer Measurements Using Thin-film Thermal Converters."

Joseph Kinard and Thomas Lipe were invited to the 2001 meeting of EUROMET AC-DC technical experts in Prague, Czech Republic, June 17–18, 2001. While at the EUROMET meeting, Kinard presented two papers describing recent developments in AC waveform synthesis using Josephson arrays, and developments in the NIST 100 A AC current shunt calibration service. Lipe presented developments in the NIST high-voltage thermal converter programs and the cryogenic AC-DC thermal transfer standard project.

Joseph Kinard presented an invited paper on the calibration of transfer shunts at NIST to the British Electrical Measurements Conference, Harrogate, Yorkshire, UK, on November 8, 2001.

Recent Publications

C. D. Reintsema, T. E. Lipe, and J. R. Kinard, "An Improved Sensor for the NIST Cryogenic Thermal Transfer Standard," Conference Digest, Conference on Precision Electromagnetic Measurements, Ottawa, Ontario, Canada, June 16-21 2002, pp. 108-109.

J. R. Kinard, T. E. Lipe, and T. F. Wunsch, "Improved High-Current Thin-Film Multi-junction Thermal Converters," Conference Digest, Conference on Precision Electromagnetic Measurements, Ottawa, Ontario, Canada, June 16-21 2002, pp. 364-365.

J. R. Kinard and T. E. Lipe, "Calibration of AC-DC Transfer Shunts at Currents up to 100 A and at Frequencies up to 100 kHz," Conference Digest, Invited Paper, British Electromagnetic Measurements Conference, Harrogate, UK, Nov 6-8 2001, AC Measurements Section.

T. F. Wunsch, J. R. Kinard, R. P. Manginell, T. E. Lipe, O. P. Solomon, and K. C. Jungling, "Recent Advances in AC-DC Transfer Measurements Using Thin-Film Thermal Converters," 2001 Measurement Science Conference Digest, Session II-B.

H. O. Wolcott, J. R. Kinard, and T. E. Lipe, "Improved Range Resistors for AC-DC Transfer Measurements," 2001 Measurement Science Conference Digest, Session II-B.

T. E. Lipe, J. R. Kinard, and C. D. Reintsema, "Improvements in the NIST Cryogenic Thermal Transfer Standard," IEEE Transactions on Instrumentation and Measurement, vol. 50, no. 2, pp. 326-329 (April 2001).

T. F. Wunsch, J. R. Kinard, R. P. Manginell, T. E. Lipe, O. P. Solomon, and K. C. Jungling, "A New Fabrication Process for Thin-Film Multi-junction Thermal Converters," IEEE Transactions on Instrumentation and Measurement, vol. 50, no. 2, pp. 330-332 (April 2001).

T. F. Wunsch, J. R. Kinard, R. P. Manginell, T. E. Lipe, O. P. Solomon, and K. C. Jungling, "Evaluation of Coaxial Single-Range Thermal Converters with Multi-junction Thin-Film Thermoelements," Proceedings of the 2001 Instrumentation and Measurement Technology Conference, May 21-23, 2001, Budapest, Hungary, pp. 449-452.

J. R. Kinard, T. E. Lipe, and S. Avramov-Zamurovic, "A New Binary Inductive Divider Comparator System for Measuring High-Voltage Thermal Converters," Proceedings of the 2001 Instrumentation and Measurement Technology Conference, May 21-23, 2001, Budapest, Hungary, pp. 2145-2148.

H. O. Wolcott, J. R. Kinard, and T. E. Lipe, "Novel High-Voltage Range Resistors for AC-DC Thermal Converters," Proceedings of the 2001 NCSL International Workshop and Symposium, July 29-August 2, 2001, Washington, DC, USA.

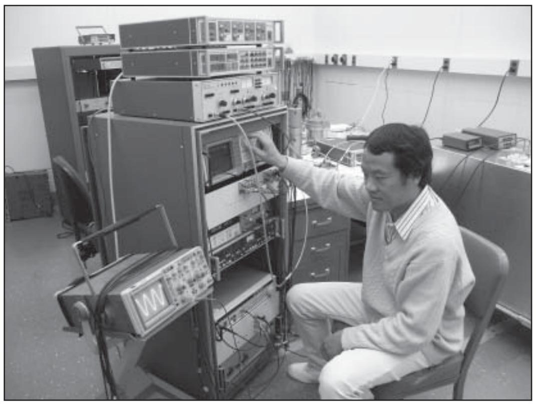
T. E. Lipe, "Recent Developments in the NIST Cryogenic Thermal Transfer Standard Project," Proceedings of the 2001 NCSL International Workshop and Symposium, July 29-August 2, 2001, Washington, DC, USA.

T. E. Lipe, "Recent Developments in the NIST AC-DC Difference Calibration Service for Thermal Transfer Standards," AUTOTESTCON 2001 Proceedings, August 20-22, 2001, Valley Forge, PA, USA, pp. 105-114.

Farad and Impedance Metrology

Goals

To maintain the Farad and tie the U.S. legal Farad to the international system of units, to support and improve NIST's impedance measurement services, and to ensure the critically needed access of the U.S. industrial base to internationally consistent, reliable, reproducible, and traceable electrical measurements.



Wang sets up an automated system for determining the frequency dependence of fused-silica capacitors.

Customer Needs

This project ties the U.S. legal system of electrical units to the International System of Units (SI) through the realization of the SI unit of capacitance. This work also forms the foundation of NIST's measurement services for electrical impedance, ensuring the sound metrological basis for all impedance measurements, both nationally and internationally, and ensuring that the claims of measurement accuracy by U.S. industries are recognized and accepted worldwide. The need continues for better representation of capacitance and also for better test and calibration tools at NIST with which to verify objectively the claims of improved performance specifications, to achieve consistency, and to help avoid technical trade barriers. A new generation of automated laboratory test systems is particularly needed at NIST for supporting improved impedance calibrations.

Technical Strategy

The primary facility for tying the U.S. legal system of electrical units to the international system of units is the NIST calculable capacitor, with which the measurement of capacitance is effectively achieved through a measurement of length. Both the calculable capacitor and the chain of high precision measurements that transfers the SI unit to the calibration laboratories must be maintained, improved, and compared with other national metrology laboratories to ensure measurement consistency on an international level.

AC measurements linking the calculable capacitor to the set of standards that comprise the National Farad Bank have been performed only at 1,592 Hz and 1,000 Hz. However, customer standards are often calibrated at other frequencies; as a result, the uncertainty provided for customer calibrations was significantly increased to account for differences in the capacitance unit due to frequency dependence. In order to better support customers' needs in the broader frequency range from 100 Hz to 20,000 Hz, the frequency dependence of the Farad Bank needs to be determined.

DELIVERABLES: By 2003, determine the frequency dependence of the National Farad Bank from 100 Hz to 20 kHz.

Many national laboratories are developing the capability to do AC quantum Hall resistance (QHR) measurements as a means to obtain a capacitance unit because of the difficulty in establishing a calculable capacitor measurement system. With the availability at NIST of the calculable capacitor, NIST is ideally situated to perform measurements to link the capacitance as determined with the AC QHR to NIST's present unit of capacitance.

DELIVERABLES: By 2004, perform SI measurements of the AC QHR via the calculable capacitor.

Development of wideband impedance measurement services requires reference standards that can be characterized over the impedance and frequency ranges of interest. NIST has developed a system to characterize commercial four-terminal-pair (4TP) capacitance standards from 1 pF to 1 nF over the frequency range from 1 kHz to 10 MHz. This system is being used to offer special tests for 4TP capacitors as well as provide reference standards for general impedance measurements using a commercial LCR meter. A bootstrapping technique using the LCR meter and an inductive voltage divider (IVD) can be used to extend the characterization from the 1 nF standard to higher-valued capacitance standards up to 10 μF. A major source of error associated with the bootstrapping technique is due to the in-phase and quadrature errors of the IVD. The newly-constructed straddling bridge will allow for the accurate self-calibration of single-decade, two-

Technical Contacts:
Yicheng Wang

Staff-Years:
4.5 Professionals
2.0 Technicians
0.8 Contractor

"I certainly think [the improvement in 1000 Hz calibrations] is a move in the right direction!"

Andeen-Hagerling, Inc.

stage reference IVDs over the 20 Hz to 100 kHz frequency range.

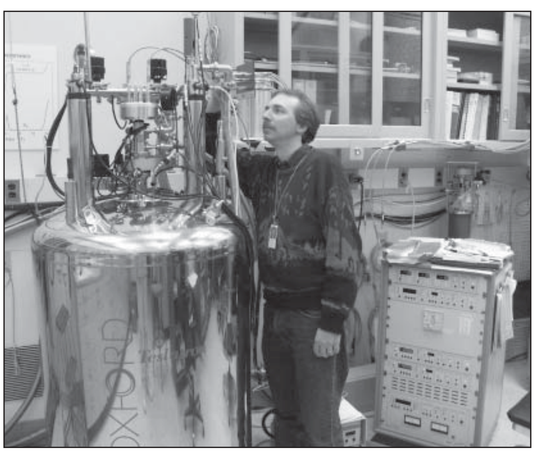
DELIVERABLES: By 2003, develop and implement a system to characterize four-terminal-pair capacitance standards of values from 1 pF to 1 μF for use as primary reference standards for measuring general impedances (inductors, capacitors, and resistors) at frequencies from 20 Hz to 100 kHz.

DELIVERABLES: By 2006, complete construction of a Capacitance Scaling Bridge for high-accuracy capacitance measurements from 50 Hz to 20 kHz.

Accomplishments

■ A direct comparison has been performed between a cryogenic capacitor having a non-nominal value (10.3 pF) with the calculable capacitor. This work proves that the quantum metrology triangle (see discussion under the Single-Electron Tunneling Project) can be closed via a comparison between a single electron tunneling (SET) based capacitor and the calculable capacitor. The results were presented at CPEM 2002 in Ottawa, Canada and have been submitted to the IEEE Transactions on Instrumentation and Measurement for publication.

■ Construction of an AC QHR measurement system has been completed, which will allow us to compare an AC QHR device with a well-characterized quadrifilar resistor and thus to determine the frequency dependence of the former. This work may lead to a quantum representation of the farad.



Scott Shields assists with the installation of the AC QHR measurement system.

■ We have characterized the nonlinearity of the AH 2500A bridge from Div 814 in Boulder for values near 10 pF using 10 pF and 1 pF standards. The results indicate that a comparison will be possible using these instruments between a cryogenic capacitor with an odd value, say 10.3 pF, and the NIST Farad Bank (and therefore, indirectly with the calculable capacitor) at an uncertainty of a few parts in 10^7. This is the first documented use of the Andeen-Hagerling bridge below its specified uncertainty of 3 ppm (with Option E). This work proves that the SET work can be done in Boulder while still maintaining a link with the calculable capacitor with very high accuracy.

■ Recent work in the Electricity Division has resulted in a factor of 3 decrease in the uncertainty for certain of the highest-level calibrations of fused-silica capacitance standards. Electricity Division staff have recently completed a detailed characterization of the transfer of the farad unit from the calculable capacitor to calibration laboratory reference standards at a frequency of 1 kHz (previously only done at 1592 Hz). As a result, the total uncertainty (95 % confidence) for the calibration of 10 pF and 100 pF fused-silica capacitance standards at 1 kHz has decreased from 1.5 ppm to 0.5 ppm.

■ We have recently completed preliminary measurements of the frequency dependence of 10 pF fused-silica capacitors from 400 Hz to 16 kHz. This will enable NIST to offer full calibration services for the new multi-frequency Andeen-Hagerling model 2700A bridge from 50 Hz to 20 kHz within the next few years.

■ A straddling bridge has been completed. The details of the design and construction have been presented at IMTC2002 in Anchorage, AK. The bridge has been used to self-calibrate two IVDs – a low-frequency (20 Hz to 20 kHz), single-decade IVD and a high-frequency (1 kHz to 1 MHz) 11-ary IVD. Preliminary results indicate that the low-frequency IVD exhibits in-phase and quadrature errors of less than ±5 parts in 10^8 of full-scale ratio at 1 kHz, increasing to ±1 part in 10^6 at 20 kHz. In addition, a method to compensate for the internal admittance loading errors of the low-frequency IVD was verified by calibrating the IVD with the straddling bridge both with and without compensating networks installed. The measurements indicate that the compensation scheme reduces the IVD's in-phase and quadrature errors by more than an order of magnitude at 20 kHz.

FY Outputs

Calibrations

200 tests were performed on 126 artifacts for 89 customers for impedance standards and inductive voltage dividers, providing income to the division of approximately $225,000 (October 1, 2001, to September 30, 2002)

Collaborations

Yicheng Wang collaborated with the Physical and Chemical Properties Division in a competence project to develop an atomic standard of pressure based on capacitance metrology.

Recent Publications

N.M. Zimmerman, M. El-Sabbagh, and Y. Wang, "Improved Cryogenic Capacitor for the ECCS: Larger Value (10 pF) and SI Measurement by Tuning the Calculable Capacitor," to be published in IEEE Trans. Instrum. and Meas., Special Issue on Selected Papers CPEM 2002.

M. El-Sabbagh, Y. Wang, N.M. Zimmerman, "A new, larger cryogenic capacitor, and a direct comparison to the calculable capacitor," Digest of Conf. of Prec. Electromag. Meas. (CPEM 2002), June 16-21, 2002, Ottawa, Canada, pp. 130-131 (June 2002).

Waltrip, Bryan C., Koffman, Andrew D., and Avramov-Zamurovic, Svetlana, "The Design and Self-Calibration of Inductive Voltage Dividers for an Automated Impedance Scaling Bridge," Proceedings of the 2002 Instrumentation and Measurement Technology Conference, Anchorage Alaska, May 21-23, 2002.

Jeffery, Anne-Marie and Koffman, Andrew D., "Improved 1 kHz Capacitance Calibration Uncertainty," Proceedings of the 2002 Instrumentation and Measurement Technology Conference, Anchorage Alaska, May 21-23, 2002.

B. C. Waltrip, O. B. Laug, and G. N. Stenbakken, "Improved Time-Base for Waveform Parameter Estimation," IEEE Trans. Instrum. Meas., 50, No. 4, pp. 981-985 (Aug 2001).

B. C. Waltrip, A. D. Koffman, and S. Avramov-Zamurovic, "A Capacitance Measurement System Using an IVD Bridge," Proc. 2001 Natl. Conf. of Standards Laboratories Intl. Workshop and Symp. (NCSLI), Jul 30-Aug 2, 2001, Washington, DC, USA (Jul 2001).

R. E. Elmquist, A.-M. Jeffery, and D. G. Jarrett, "Characterization of Four-Terminal-Pair Resistance Standards: A Comparison of Measurements and Theory," IEEE Trans. Instrum. Meas. Special Issue on Selected Papers CPEM 2000, 50, No. 2, pp. 267-271 (Apr 2001).

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A. Jeffery, "Report on the CCEM Comparison of 10 pF Capacitance Standards," Digest for Conf. on Precision Electrical Measurements (CPEM 2000), May 14-19, 1999, Sydney, Australia, pp. 327-328 (May 2000).

A. Jeffery, J.Q. Shields, and S.H. Shields, "A Multi-Frequency 4-Terminal-Pair AC Bridge," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2000), May 14-19, 2000, Sydney, Australia, pp. 437-438 (May 2000).

R.E. Elmquist, A. Jeffery, and D.G. Jarrett, "Characterization of Four-Terminal-Pair Resistance Standards: A Comparison of Measurements and Theory," Digest of Conf. on Precision Electromagnetic Measurements (CPEM 2000), May 14-19, 2000, Sydney, Australia, pp. 439-440 (May 2000).

R.E. Elmquist, "Calculable Coaxial Resistors for Precision Measurements," IEEE Trans. Instrum. Meas., 49, No. 2, pp. 210-215 (Apr 2000).

S. Avramov-Zamurovic, A. D. Koffman, N. M. Oldham, and B. C. Waltrip, "The Sensitivity of a Method to Predict a Capacitor's Frequency Characteristic," IEEE Trans. Instrum. Meas. , 49, No. 2, pp. 398-404 (Apr 2000).

A. D. Koffman, S. Avramov-Zamurovic, B. C. Waltrip, and N. M. Oldham, "Uncertainty Analysis for Four Terminal-Pair Capacitance and Dissipation Factor Characterization at 1 MHz and 10 MHz," IEEE Trans. Instrum. Meas., 49, No. 2, pp. 346-348 (Apr 2000).

N. Oldham, T. Nelson, R. Bergeest, R. Carranza, M. Gibbes, K. Jones, G. Kyriazis, H. Laiz, L. Liu, Z. Lu, U. Pogliano, K. Rydler, E. Shapiro, E. So, M. Temba, and P. Wright, "International Comparison of 50/60 Hz Power (1996-1999) Digest for Conf. on Precision Electrical Measurements (CPEM 2000), May 14-19, 1999, Sydney, Australia, pp. 66-67 (May 2000).

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L. B. Baca, L. Duda, R. Walker, N. Oldham, and M. Parker, "Internet-Based Calibration of a Multifunction Calibrator," Proc. 2000 Natl. Conf. of Standards Laboratories Intl. Workshop and Symp. (NCSL), Jul 16-20, 2000, Toronto, ON, Canada (Jul 2000).

H. Sanchez, J. Cioffi, H. Laiz, D. Bennett, H. Ferreira, R. Ortega, N. Oldham, and M. Parker, "SIM Comparison of Electrical Units," Proc. Metrologia-2000 Conference, Dec 4-7, 2000, Sao Paulo, Brazil, http://www.sbmetrologia.org.br/metrologia2000 (Dec 2000).

Pulse Metrology and Time Domain Measurements

Goals

To expand and improve present NIST time domain waveform measurement services to support high performance samplers and digitizers, as well as fast pulse and impulse sources, operating at frequencies from DC to 50 GHz.

Bryan Waltrip and Robert Palm evaluate the performance of the NIST-developed Wideband Sampling Voltmeter and its associated input probes for making accurate pulse waveform measurements.

Customer Needs

The U.S. electronic instrumentation and test equipment industry is maintaining its world position through the development and deployment of increasingly accurate, easier-to-use arbitrary waveform generators, fast electrical pulse/impulse sources, waveform samplers, and high-speed digitizers. To prove their accuracy in a highly competitive environment, manufacturers and users need objective calibration methods and standards that are traceable back to the derived electrical units maintained and disseminated by NIST. There is a need for better means of characterizing the parameters of pulse and arbitrary waveform generators, the power spectrum of impulse generators, the step response of fast digitizers, and the delay in coaxial delay lines. Manufacturers and users of high-performance data converters have developed a performance standard (IEEE Std. 1241) with which to objectively compare such devices and have expressed the need for calibration support at NIST.

Technical Strategy

Accurate measurements of arbitrary waveform parameters, from basic root-mean-square (rms) values to crest factor, signal-to-noise ratio (SNR), harmonic distortion, etc. have been realized at NIST using a specially designed strobed analog comparator device. Success with the first generation custom integrated circuit implementation has led to the development of two separate and distinct comparator-based probes for accurate waveform sampling from power-line frequencies to 5 GHz. One of the new probes is fabricated in a fast bipolar silicon process with a cutoff frequency, f_T, of 28 GHz and uses a circuit architecture refined from the previous design. The other probe is built for lower speed operation but with a wider input range, higher input impedance, and much lower noise.

DELIVERABLES: By 2003, complete development and deliver to the Air Force a complete waveform sampling system and associated application software to control the calibration of a commercial, automated AC measurement standard.

Various pulse measurement systems have been developed at NIST for purposes of providing Special Test services for impulse generators. The system used in the 65100S Impulse Spectum Amplitude Special Test presently used for calibration of impulse generators is beginning to show signs of performance, reliability, and software obsolescence, which makes the need for an improved version imperative to keep the costs of providing these NIST services reasonable.

DELIVERABLES: By 2003, develop a measurement system that can provide a more flexible, self-documenting, and automated system for performing the SP250 65100 series tests.

DELIVERABLES: By 2003, complete documentation on the 65200S Fast Repetitive Pulse Transition Duration Parameters Special Test as to formalize it as a NIST calibration service.

DELIVERABLES: By 2004, complete documentation on 65100S Impulse Spectrum Amplitude Special Test as required to formalize it as a NIST calibration service.

Accurate measurements of the impulse response of high-speed samplers requires very short duration electrical pulses. Analogously, accurate measurement of the parameters of high-speed electrical pulses requires having an accurately calibrated sampler. In conjunction with the EEEL Optoelectronics Division in Boulder, we will examine the possibility of using a photodiode as a possible pulse generator for calibration of the 65200S samplers. The primary issue for use of the photodiode will

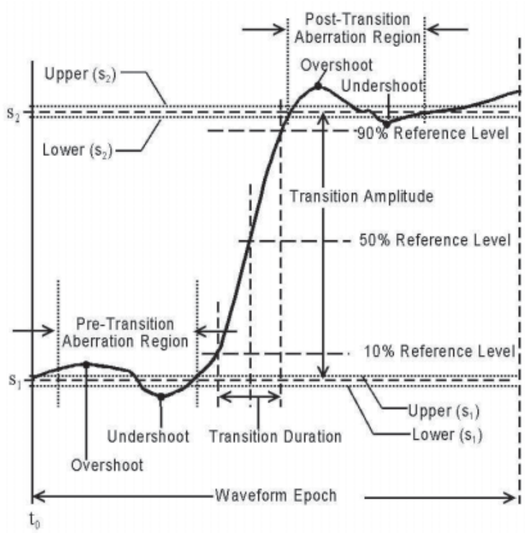
Technical Contact:
Nicholas G. Paulter, Jr.

Staff-Years:
3.0 Professionals
1.0 Technician
0.8 Contractor

"The new digitizer calibration system developed by NIST's Electricity Division enables Sandia to calibrate digitizers using well characterized pulse inputs for the first time. The digitizers support critical pulse voltage and pulse current measurements ... NIST staff developed specific calibration procedures for Sandia digitizers, as well as an uncertainty analysis for the calibration process."

Richard B. Pettit, Manager
Primary Electrical Standards
Sandia National Laboratories

be the ability to provide an accurate uncertainty estimate of its output pulse.



Some of the pulse waveform parameters defined by international standards and measured by NIST's 65200S calibration service.

The nose-to-nose sampler calibration method is presently being used to calibrate the 65200S Fast Repetitive Pulse Transition Duration Special Test samplers, and this method may be extendable to the now commercially available 70 GHz samplers. Extending our service to make use of the 70 GHz sampler will require assessment of these samplers and evaluation of the uncertainty associated with their use.

The performance parameters of high-speed devices, such as samplers, are often measured and quoted in both the time and frequency domains. Presently, there is no method for mapping the uncertainties for typical waveforms from one domain to the other. The ability to perform such mapping, and taking advantage of improved signal to noise or lower uncertainty in either domain, may improve the published uncertainties for our special test services.

DELIVERABLES: By 2003, assess the suitability of a high-speed photodiode as a pulse generator for calibration of the 65200S Fast Repetitive Pulse Transition Duration Special Test samplers.

DELIVERABLES: By 2004, implement nose-to-nose sampler calibration using 70 GHz samplers.

DELIVERABLES: By 2005, assess ability to map uncertainties from one measurement domain to the other.

A precision time delay system is being developed. Using an input strobe, the system will provide three electrical output pulses where one of the output pulses can be delayed relative to the others by an amount from tens of femtoseconds to tens of milliseconds. The uncertainty in the delay will be on the order of femtoseconds for delays less than 1 ns and a few picoseconds for longer delays. The delay system will expand the measurement range of and reduce the uncertainties in the SP250 65400S Pulse Delay Time Interval series tests, reduce the uncertainties in the 65100S series tests, and will be used to develop cycle-to-n^{th}-cycle jitter measurement capability, which is an important performance parameter in digital telecommunications and computing systems.

DELIVERABLES: By 2003, develop programmable time delay system with tens of femtoseconds to tens of millisecond delay capability.

Accomplishments

- Assessments were made of the Fast Repetitive Pulse Transition Parameters Special Test service, SP250 65200S, which is used for measurements of the step response of high-speed (transition duration $\leq$ 350 ps) samplers and output characteristics of high-speed pulse generators. This assessment shows that the uncertainty in transition duration can be reduced from the presently published value of $\pm$ 1.5 ps to $\pm$ 1.25 ps and that in pulse amplitude can be reduced from $\pm$ 2 mV to $\pm$ 1.5 mV.

- NIST and the National Physical Laboratory (NPL), United Kingdom, completed an interlaboratory comparison of their pulse measurement services. This comparison verified that the two services provide similar results. The differences between the laboratories are within the published uncertainties for transition duration and pulse amplitude. The differences are dominated by the different impulse responses and impulse response estimates of the samplers used and the waveform reconstruction process used.

- The nose-to-nose (ntn) sampler calibration method implemented by the Electricity Division in Gaithersburg, Maryland and the Optoelectronics Division in Boulder, Colorado was compared. The results of this comparison show that the magnitude and phase spectra generated by the two laboratories agree within observed measurement variation. Similar agreement was found for the time-domain parameter of transition duration.

- Five low-frequency sampling comparator probes have been fabricated and packaged. Two were delivered to Sandia National Laboratories who will use them for calibrating oscilloscopes used to measure voltage pulses of microsecond duration with peak amplitudes of 100 V. The measurement system's sensitivity uncertainty at 100 V is less than 0.2 %. Also delivered along with the probes were two custom designed 100 V, 20:1 attenuators, a NIST-designed Wideband Sampling Voltmeter (WSV) mainframe, and application software to facilitate oscilloscope calibration. Compared to the existing wideband sampling comparator probe, the new low frequency probe design provides higher input impedance (1 MΩ), lower noise (< 55 μV rms), a wider input voltage range (±10 V), better linearity (< 10 μV/V), and comparable gain flatness over the 10 Hz to 100 kHz frequency range (10 μV/V). These electrical characteristics are needed to support NIST Special Test and Calibration services for pulse settling, distorted power, impedance, and amplitude flatness. Other NIST customers who are funding probe development anticipate its use toward the calibration of a commercial automated AC voltage measurement standard.

FY Outputs

Calibrations

14 tests performed on 14 items for 9 companies and government agencies with approximately $26,600 income received. (October 1, 2001, to September 30, 2002)

Collaborations

An on-going intercomparison with the National Physical Laboratory (NPL) was continued regarding high-speed electrical pulse parameters.

The Electricity Division continues its interactions with the Law Enforcement and Justice communities, through the EEEL Office of Law Enforcement Standards, to support the detection of concealed weapons.

An intercomparison of the nose-to-nose technique for high-speed sampler characterization was made between the Electricity Division in Gaithersburg, Maryland and the Optoelectronics Division in Boulder, Colorado. Although the laboratories use different waveform averaging approaches, the results were in agreement within acceptable limits.

Standards Committee Participation

IEEE I&M Society TC-10 - N. Paulter, D. Larson, B. Waltrip, and D. Bergman participate as members of the TC-10 on Waveform Measurement and Analysis and the subcommittees on Waveform Recorder, A/D Converters, and Pulse Techniques.

N. Paulter participates as chair of the D-21b (High-Frequency Board Design) and D-21c (High-Frequency /High-Speed Controlled Impedance) IPC task groups and as chair of the IEEE Subcommittee on Pulse Techniques (SCOPT).

Recent Publications

J. Baker-Jarvis, R. Kaiser, M.D. Janezic, N.G. Paulter, and K.L.. Sticklett, NIST Technical Note 1514, “Metal Detector Studies: Research Materials,” Technology Administration, U.S. Department of Commerce (August 2002).

N.G. Paulter, D.R. Larson, and J.J. Blair, “The status of the IEEE standard on transitions, pulses, and related waveforms,” IEEE Instrumentation and Measurement Technology Conference, Anchorage, USA, 21-23, May 2002.

N.G. Paulter and D.R. Larson, “NIST’s high-speed pulse measurement service,” IEEE Instrumentation and Measurement Technology Conference, Anchorage, USA, 21-23 May 2002.

D. I. Bergman, B. C. Waltrip, “A Low Noise latching Comparator Probe for Waveform Sampling Applications,” Proc. of 19th Instrumentation and Measurement Technology Conference (IMTC/2002), May 21-23, 2002, Anchorage, AK, pp.309-314 (May 2002).

N.G. Paulter, “Walk-through Metal Detectors for Use in Concealed Weapon and Contraband Detection,” National Institute of Justice Standard-0601.02, National Institute of Justice, U.S. Department of Justice (April 2002).

N.G. Paulter and D.R. Larson, “Pulse parameter uncertainty analysis,” Metrologia, Vol. 39, pp.143155, (2002).

N.G. Paulter and D.R. Larson, “An Examination of the Spectra of the “Kick-out” Pulses for a Proposed Sampling Oscilloscope Calibration Method,” IEEE Transactions on Instrumentation and Measurement, Vol. 50, pp. 1221 – 1223, (October 2001).

N. G. Paulter, Jr., “An Assessment on the Accuracy of Time-domain Reflectometry for Measuring the Characteristic Impedance of Transmission Lines,” IEEE Trans. on Instrum. and Meas., 50 No. 5, pp 1381-1388 (Oct 2001).

N. G. Paulter and D. R. Larson, “An Uncertainty Analysis of the High-Speed Pulse Parameter Measurements at NIST,” to be published in Proc. of IMEKO TC-4 Symposium and ADC Workshop, Lisbon, Portugal, Sep 13-14, 2001.

D. R. Larson and N. G. Paulter, “Using the Nose-to-Nose Sampler Calibration Method in Pulse Metrology,” to be published in Proc. of IMEKO TC-4 Symposium and ADC Workshop, Lisbon, Portugal, Sep 13-14, 2001.

J. B. Jarvis, M. D. Janezic, B. Riddle, C. L. Holloway, N. G. Paulter, and J.E. Blendell, NIST Technical Note 1520 “Dielectric and Conductor-Loss Characterization and Measurements on Electronic Packaging Materials,” (July 2001).

O. M. Solomon, Jr., D. R. Larson, and N. G. Paulter, “Comparison of Some Algorithms to Estimate the Low and High State Level of Pulses,” Proc. of 18th Instrumentation and Measurement Technology Conference (IMTC/2001), May 21-23, 2001, Budapest, Hungary, pp. 96-101 (May 2001).

N. G. Paulter, E. N. Grossman, G. N. Stenbakken, B. C. Waltrip, S. Nolen, and C. D. Reintsema, "Design of an Active MM-Wave Concealed Object Imaging System," Proc. of SPIE Conf. on Passive Millimeter-wave Imaging Technology V, 4373, Apr 19, 2001, Orlando, FL, pp. 64-71 (2001).

E. N. Grossman, S. Nolen, N. G. Paulter, and C. D. Reintsema, "Concealed Weapons Detection System Using Uncooled, Pulsed, Imaging Arrays of Millimeter-Wave Bolometers," Proc. of SPIE Conf. on Passive Millimeter-wave Imaging Technology V, 4373, Apr 19, 2001, Orlando, FL, pp. 7-15 (2001).

N. G. Paulter and D. R. Larson, "Improving the Uncertainty Analysis of NIST's Pulse Parameter Measurement Service," 56th ARFTG Conf. Digest, Metrology and Test for RF Telecommunications, Automatic Radio Frequency Techniques Group, Nov 30-Dec 1, 2000, Boulder, CO, pp. 16-24 (Nov 2000).

W.-l. Cao, M. Du, C. H. Lee, and N. G. Paulter, "High Frequency and Broadband Signal Measurements by Ultrafast Opto-Microwave Intermixing and Sampling," Intl. Topical Meeting on Microwave Photonics MWP 2000, Sep 11-13, 2000, St. John's College, Oxford, UK, organizer-Inst. of Electrical Engrs. (UK), pp. 207-209 (Sep 2000).

Electric Power Metrology

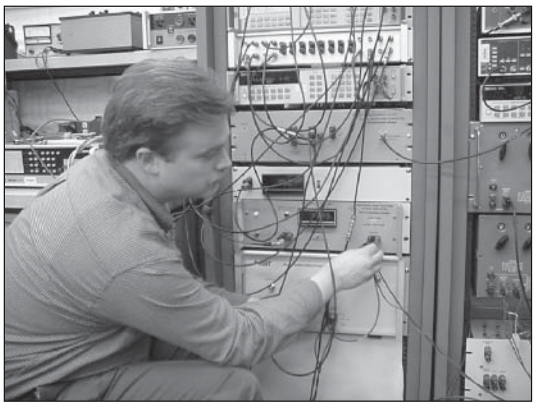
Technical Contact:
Gerard N. Stenbakken

Staff-Years:
4.5 Professionals
0.5 Guest Researcher
0.5 Technician

Goals

To maintain and disseminate precision electrical measurements, high voltage, high current, and power, in support of U.S. industry for such applications as the transmission and distribution of electric power and high current welding.

To assess and develop new measurement technologies for the increased reliability and quality of the U.S. electric power system.



J. Chandler adjusts the NIST AC Power Bridge.

Customer Needs

The fair and reliable transmission and distribution of electric power requires accurate and traceable measurements of electrical quantities. Electrical energy metering throughout the U.S. is traceable to NIST calibrations and results in annual revenues exceeding $240 billion. To ensure the accurate measuring and monitoring of electric power, U.S. industry requires traceable calibration services of AC, and DC high voltages, high currents, power, and energy. To maintain reliable delivery of electric power and to compete in an international market, U.S. utilities and industry require support in developing technically sound international standards governing the use of technologies related to electric power.

With deregulation of the electric power industry, new diagnostic technologies are needed to ensure the reliability of the increasingly complex U.S. electric power infrastructure. New web-based sensor technologies raise questions of security and access to power system information and control by unauthorized persons. For consumers, the expanding usage of sensitive microelectronic devices increases the need for high-quality power. Additionally, economic and environmental pressures are motivating the drive toward more efficient electrical devices. Activities in this project provide the support required by the electric power and electric equipment industries to maintain the security and reliability while utilizing new cost-saving measurement technologies related to the transmission, distribution, and use of electric power. To support industry efforts to protect this critical infrastructure, computer security vulnerabilities of power grid control systems are being identified and the standards affected by these vulnerabilities are being reviewed. A testbed is being built to develop more secure control system communication techniques and to verify that they still meet the real-time requirements of the standards.

Technical Strategy

This project supports the electric power industry by maintaining calibration services in the areas of high voltage, high current, power, and energy. These services are continually improved to meet the changing measurement needs of U.S. industry. The technical expertise utilized in providing these services is applied to the development of key national and international standards.

This project maintains the U.S. standard for power and energy, which is used by utilities and meter manufacturers to ensure the accurate sale of electric power in the U.S. In order to improve NIST's ability to perform measurements for systems containing harmonics, a new automated sampling test system is being constructed to replace the aging manual current comparator system currently in use.

DELIVERABLES: By 2003, perform intercomparison of harmonic power measurements with NRC-Canada.

DELIVERABLES: By 2004, complete construction of automated sampling test system and begin use for customer power and energy meter calibrations up to 100 A and 600 V.

International comparisons are essential for the validation of measurement techniques used at National Metrology Institutions. To ensure the accurate measure of power in North and South America, NIST will serve as the pilot lab for an intercomparison between SIM countries.

DELIVERABLES: By 2004, complete SIM power and energy measurement intercomparison.

New power generators now have mandatory access to the power grid under deregulation. When the

"The aggregate annual economic impact [for not having adequate measurements and standards in place for the electric power industry] range from $3.1 to $6.5 billion."

"Changing Measurements and Standards Needs in a Deregulated Electric Utility Industry," NIST Planning Report 00-2

market price is favorable, they can produce high levels of electric power, but when unfavorable market prices exist, they go into housekeeping mode and become consumers of low levels of power. The large difference in power levels that exist depending upon whether they are power producers or consumers demands a wider dynamic range for power/energy metering. It also requires that power flow must be metered both into the generating plant when in housekeeping mode, or out of the plant when it is operating as power producer.

DELIVERABLES: By 2004, develop calibration capability for low power metering down to 120 V, 10 mA.

Electric power generation, transmission, and distribution comprise an infrastructure that enables the motor of modern society to run. Any interruption of electric power creates at a minimum an inconvenience, but can be life-threatening. There has been a proliferation of modem- and web-connected sensors and actuators used to control the operation of electric power systems. Because they are designed to meet functional specifications such as speed and not security considerations, the communications among them may be vulnerable to attack and inadvertent or malicious misoperation. NIST is identifying the security weaknesses of these process control systems in an attempt to raise industry awareness of the potential vulnerabilities and to establish a set of security requirements for power system controls and communications.

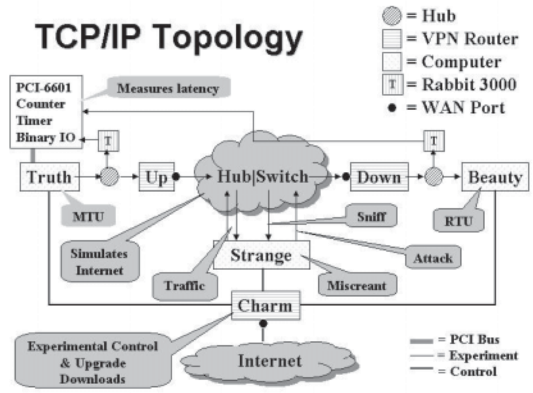
DELIVERABLES: By 2003, develop a testbed and test procedures to measure the latency and jitter of RS232 channel security modules.

DELIVERABLES: By 2004, help industry define standards for security modules used in control loops.

In an effort to reduce the consumption of electric power, the U.S. Department of Energy (DOE) designates minimum efficiencies of electrical equipment. Distribution power transformers and electric motors are two categories of equipment for which DOE is developing efficiency standards. NIST is advising DOE by developing technically sound sampling strategies and instrumentation for the testing of these devices.

DELIVERABLES: By 2003, perform, field test using the NIST developed portable system for testing the efficiency of distribution transformers.

DELIVERABLES: By 2004, contribute to DOE final rule for the efficiency of fractional horsepower motors.



Topology of testbed under development for evaluating security of serial electric power control systems.

Accomplishments

■ The National Rural Electric Cooperative Association (NRECA) has published a guide written by François Martzloff of the Electricity Division aimed at helping the utility customer service representatives and customers communicate better and quickly identify the causes of their power problems. Solving problems over the telephone rather than traveling long distances for a site visit is an important factor in reducing the costs and time spent correcting power quality problems. The guide is now being disseminated with great success among the member utilities of NRECA.

■ An objective review entitled The Power Quality Implications of Conservation Voltage Reduction (see www.epri.peac.com) has been made by Francois Martzloff of the Electricity Division for publication by EPRI. Conservation voltage reduction (CVR) was an approach to avoiding the "rolling blackouts" (rotating power outages) that was under consideration by the State of California. The report urges cooperation among equipment manufacturers and users, together with electric utilities and regulatory agencies, supported by an objective test program on the possible side effects of CVR. The report serves to raise awareness of the possible negative consequences to power quality before CVR is implemented.

■ Under the project for Critical Infrastructure Protection (CIP), one method being recommended to improve the security of public utilities is to add encryption to all control loops that pass through public facilities. This requires an analysis of the effects of such a modification on control loop performance. To provide the utilities with the information they need for this purpose, a testbed has been designed to measure the latency and jitter caused by the use of encryption modules in typical control loop communication channels. The equipment for this testbed has been obtained and the testbed is being assembled. The initial testbed design will accommodate RS232 and Ethernet channels, the two most commonly used communications methods currently used by the utilities. Additional channel protocols used by utilities will be added later.

■ To ensure that everyone can make use of the timing data from the testbed, a standard is needed to describe how the measurements are being made. In collaboration with utility industry associations and encryption module manufacturers, preliminary test procedures have been developed for measuring the impact of encryption technology on control loop performance. To provide a context for this information, the performance characteristics of typical utility control communications channels without security measures have been analyzed. These characteristics will be used for comparison with measurements of secured channels.

■ A new test set was developed for the current transformer calibration system. This new system extends the range of frequencies over which calibrations can be provided and simplifies the operation of the system.

■ A prototype system for measuring transformer power losses was designed, assembled, and tested. It is intended to be a low-cost measurement system having sufficiently low measurement uncertainties that is capable of demonstrating the compliance of distribution transformers with energy efficiency regulations now under development by the Department of Energy. The results demonstrated that the design criterion of 0.1 % or less error for power loss measurements was met.

■ Draft B for the CCEM-sponsored power comparison was completed and posted on the website at: http://www.velocecorp.net/business/nist/ccem.

FY Outputs

Calibrations

Calibrations were performed for 46 companies and government agencies with approximately $140,000 income received. (October 1, 2001 to September 30, 2002).

Standards Committee Participation

IEEE Instrument Transformer Subcommittee (C57.13): T. L. Nelson is the Working Group Chair in charge of the revision of the IEEE Standard on Requirements for Instrument Transformers.

ANSI/NEMA Electricity Metering Committee (C12): T. L. Nelson served as the chair in FY02.

IEEE Electricity Metering Subcommittee: T. L. Nelson served as secretary in FY02.

IEEE Industrial Applications Society, Electric Machines Committee: K. L. Stricklett chaired the working group updating IEEE P114, the “Draft Standard Test Procedure for Single-Phase Induction Motors.”

IEEE Power Engineering Society Surge Protection Devices Committee: F. D. Martzloff served on multiple working groups of this committee, including working groups on Surge Characterization, Multiport Surge Protective Devices, and Secondary Arrestors.

IEC Technical Committee 81 on Lightning Protection: F. D. Martzloff served as the official delegate of the U.S. National Committee.

IEEE Power Engineering Society Power Systems Instrumentation and Measurement Committee: G. J. FitzPatrick served as the Secretary of the Committee and Secretary of the Optical Sensors Subcommittee.

American Welding Society: E. D. Simmon served on the Resistance Welding Committee.

Recent Publications

F. D. Martzloff, “Surge Protection in Low-Voltage AC Power Circuits – An Anthology Part 3: Recorded Surge Occurrences and Surveys,” (NISTIR 6714-3) 110 pages (July 2002).

E. So, R. Arseneau, D. Bennett, T.L. Nelson, and B.C. Waltrip, “NRC - NIST Intercomparison of Calibration Systems for Current Transducers with a Voltage Output at Power Frequencies,” Conference Digest 2002 Conference on Precision Electromagnetic Measurements, (CPRM 2002), pp. 544 – 544 (June 2002).

F. D. Martzloff, “Surge Protection in Low-Voltage AC Power Circuits – An Anthology Part 2: Development of Standards - Reality Checks,” (NISTIR 6714-2) 190 pages, (December 2001).

E. D. Simmon, and G. J. FitzPatrick, “High Voltage and Current Metrology at NIST. Precision Measurements of the Past, Present, and the Future,” Conference on Electrical Insulation and Dielectric Phenomena, 2001 Annual Report, pp. 277 – 280 (Oct. 2001).

M. Misakian, O. Petersons, J. J. Kasianowicz, and B. Robertson, “Frequency Response of Alternating Currents through the Staphylococcus aureus alpha-hemolysin Ion Channel,” Bioelectromagnetics, **22**, pp. 487-493 (Oct., 2001).

E.D. Simmon and G.J. FitzPatrick, ”Optical Current Transducers for Electric Power Systems: Overview and Literature Survey,” NISTIR 6805, 157 pages (Sept 2001).

F. D. Martzloff, “Surges Happen! How to Protect the Appliances in Your Home,” NIST recommended practice SP 960-6, Natl. Inst. Stand. Technol. 20 Pages (May 2001).

N. Oldham, T. Nelson, R.Bergeest, G. Ramm, R.Carranza, A. Corney, M.Gibbes, G.Kyriazis, H.Laiz, L.Liu, Z. Lu, U. Pogliano, K.Rydler, E.Shapiro, E. So, M.Temba, and P.Wright, “An International Comparison of 50/60 Hz Power (1996-1999),” IEEE Trans. Instrum. Meas. vol. 50, no. 2, pp. 356-360 (April, 2001).

E. So, D. Angelo, T. Nelson, and L. Snider, “NRC - NIST Intercomparison of Power Meter Calibrations at 60 Hz and Ranges up to 600 V, 100 A,” IEEE Trans. Instrum. Meas., vol 50, no. 2, pp. 353-355 (April 2001).

E.D. Simmon, G.J. FitzPatrick, and O. Petersons, “A Users’ Guide to the NIST Capacitance Ratio Bridge,” NIST Technical Note #1442, 75 pages (April 2001).

K.L. Stricklett and J. Baker-Jarvis, “Electrical Properties of Biological Materials”: A Bibliography Survey, NISTIR 6564 Natl. Inst. Stand. Technol. 24 Pages (Oct 2000).

K.L. Stricklett, “Electrical coupled hydrodynamic flows,” Proc. 2000 Annual Report Conference on Electrical Insulation and Dielectric Phenomena. Canada (Oct 2000).

T.S. Key, D. Nastasi, K. Phipps, and F.D. Martzloff, “Some Enlightening Case Histories on Lightning Damage,” Proc. of 25th Intl. Conf. on Lightning Protection, Rhodes, Rion, Greece (Sept. 2000).

F.D. Martzloff, “The Trilogy Update of IEEE Std. C62.41,” Proc. of 25th Intl. Conf. on Lightning Protection, Rhodes, spon. High Voltage Laboratory, Univ. of Patras, Rion, Greece (Sept. 2000).

F.D. Martzloff, “On the Dispersion of Lightning Current after a Direct Flash to a Building,” Proc. of 25th Intl. Conf. on Lightning Protection, Rhodes, Univ. of Patras, Rion, Greece (Sept. 2000).

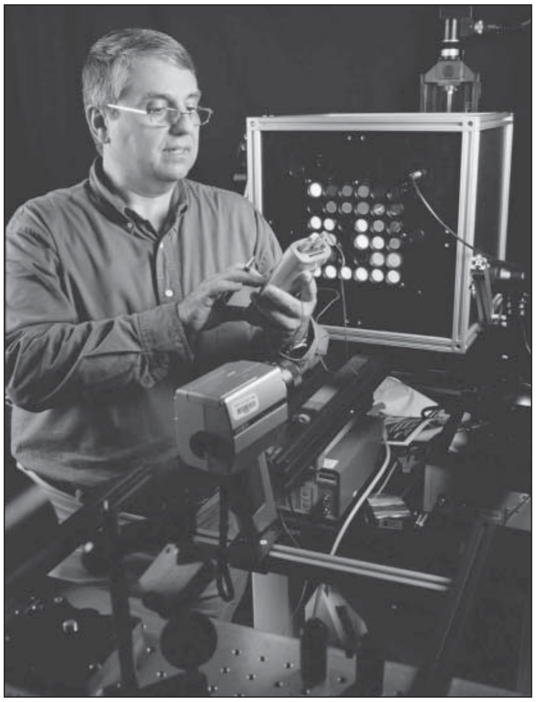
F.D. Martzloff, “A New IEC Standard on the Measurement of Power Quality Parameters,” Proc. EMC Europe 2000 Symposium, Brugge, Belgium (Sept. 2000).

F.D. Marzloff and K. Phipps, “A Novel Transducer for Monitoring Surge in AC Mains: Expectations and Reality,” Proc. EMC Europe 2000 Symposium, Brugge, Belgium, (Sept. 2000).

Flat Panel Display Metrology

Goals

To develop robust, reproducible, and unambiguous metrology methods to characterize electronic displays – particularly flat panel displays (FPDs) – to support the domestic industry of display users.



John Libert prepares to record temperature changes of a filter array during operation of the tungsten-halogen lamps used to provide illumination for the next generation DMATS.

Customer Needs

The United States is a major buyer of electronic displays for computer, consumer, automotive, and avionics use. A well-defined method for specification and verification of display quality is necessary to enable worldwide commerce of displays. Sound metrology is urgently needed in this highly competitive environment of new and emerging display technologies. Further, universally recognized and accepted standards documents are needed to provide customers with tools to use in choosing the best display for their application.

Technical Strategy

This project is concerned with display metrology in general and there are numerous ongoing tasks. However, specific issues identified by industry as particularly important are being emphasized in our research.

We are working to develop and refine measurement procedures in support of ongoing electronic display metrology, and applying the results in the development of national and international standards for flat panel display characterization.

DELIVERABLES: By 2003, provide the Video Electronics Standards Association with a complete set of patterns for display measurements and set up for all pixel-array formats currently in use (approximately 40,000 patterns).

DELIVERABLES: By 2003, assist in the grand revision of the ISO visual display ergonomic standards.

DELIVERABLES: By 2004, update the NIST setup patterns with more detailed patterns that will fully test displays' abilities to accurately render details (work done in collaboration with Sun Microsystems).

The characterization of the three components of reflection (Lambertian, specular, and haze) associated with displays is being developed. Development and implementation of robust metrics is needed to characterize display reflection performance under actual conditions, e.g., the readability of automotive displays in high ambient light conditions.

DELIVERABLES: By 2003, publish a summary report detailing robust reflection measurement methods appropriate to the display industry.

DELIVERABLES: By 2003, prepare a short course for the Society of Information Display International Symposium that emphasizes reflection measurements.

DELIVERABLES: By 2003, prepare an in-house course on display metrology that provides hands-on laboratory measurements.

DELIVERABLES: By 2004, teach the in-house course on display metrology at least once each year up to four times per year.

DELIVERABLES: By 2004, prepare reflection samples to simulate common flat panel display surfaces and conduct interlaboratory comparisons with industry (collaborative effort with NIST's Optical Technology Division).

DELIVERABLES: By 2005, analyze and publish how successful our variable-radius-source method is in capturing the specular component and haze peak in making robust reflection measurements. (This will also be a collaborative effort with NIST's Optical Technology Division.)

To determine the measurement capabilities of participating laboratories in an inter-laboratory comparison effort, this project has developed a

Technical Contact:
Edward F. Kelley

Staff-Years:
3.0 Professionals
1.0 Student

"The Flat Panel Display Measurements Standard, Version 2.0 is an outstanding technical document. It offers a wealth of clearly specified and richly detailed procedures for measurement of virtually all characteristics which determine flat-panel display performance."

Louis D. Silverstein
Chief Scientist
VCD Sciences, Inc.

multi-filter source – display measurement assessment transfer standard (DMATS) – that can be passed among participating laboratories. The combination of all the targets will stress the capabilities of most laboratories in making conventional luminance and color measurement. Typical light-source calibrations involve only a white point. These new standards include the white point and much of the color gamut. A simplified version of this apparatus employing filter wheels instead of a filter array has been developed – the gamut assessment standard (GAS). The DMATS/GAS solution is essential to resolving issues of color transportability in E-commerce by assuring that the color measurement instrumentation employed is sufficiently reliable to discriminate color differences. This program is conducted in collaboration with the Physics Laboratory's Optical Technology Division.

DELIVERABLES: By 2003, investigate the design of a robust light source for using in the gamut assessment standard (GAS) and conduct at least one interlaboratory comparison with another national metrology institute.

DELIVERABLES: By 2004, refine the GAS apparatus and make multiple units to conduct general interlaboratory comparisons on a regular basis with industry.

DELIVERABLES: By 2005, have in place a general program to conduct interlaboratory comparisons based upon DMATS and GAS apparatus for any interested industrial laboratories.

In order to reduce stray-light contributions to the reference image and enable more accurate luminance measurements of complicated scenes involving high contrasts, a liquid-filled camera is under development that simulates the optics of the human eye.

DELIVERABLES: By 2003, investigate a third-generation eyeball-like camera and report progress at an industry conference.

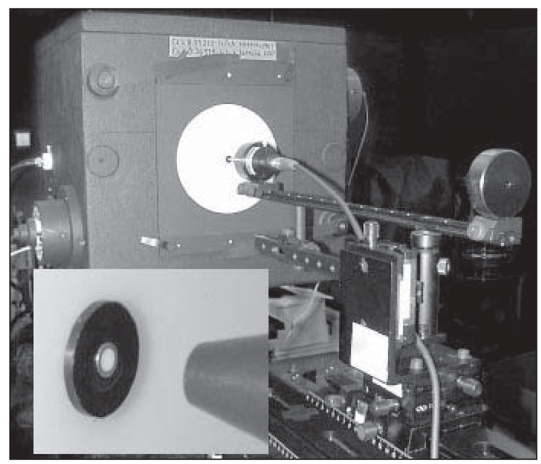
DELIVERABLES: By 2004, investigate the use of the eyeball-like camera in accurately measuring near-eye displays and report results at an industry conference.

Accomplishments

■ The second public version of the VESA Flat Panel Display Measurements Standard (FPDM2) was published with major contributions from NIST. The new document contains revised reflection measurement discussions, measurements of the geometrical imperfections of projection systems, detailed grayscale measurements, a color-gamut area metric, new setup patterns (based upon a NIST collaborative development with Sun Microsystems), and a numerous other enhancements to the first version.

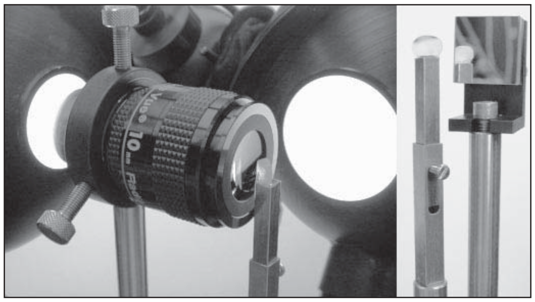
■ The Display Measurement Assessment Transfer Standards (DMATS) task was enhanced with the addition of the gamut assessment standard (GAS). An initial interlaboratory comparison using the GAS was made with NPL whereby the encouraging results were reported at a technical conference.

■ NIST has demonstrated how stray light can seriously affect results of small area measurements. Narrow-frustum-SLET (stray-light-elimination-tube) probes have been employed by medical-radiological researcher to attempt to make such small area measurements. A diagnostic apparatus for determining the limitations and successes of the use of such probes has been developed.



Measurement apparatus for testing probes used to characterize medical displays. Inset shows the tip of the probe pointing at the illuminance head (small white disk) that measures the back-reflection from the probe.

■ Preliminary diagnostic techniques were introduced to provide accurate measurements of the luminance observed in near-eye displays (NEDs). These diagnostics included: (1) the use of a small mirror between the eye and the eyepiece of a NED where the mirror observed an adjustable light source to be compared with the full-screen color viewed through the NED; and (2) an adjustable iris placed between the NED eyepiece and the detector can determine that the ray bundle used in the measurement is consistent with the ray bundle used by the eye.



A small beveled mirror placed near the eyepiece of a near-eye display (NED) with an adjustable source to the side can be used to quantify the accuracy of measurement apparatus that claims to be able to measure the light output of NEDs.

■ An invited "Short Course" on Display Metrology was presented at the Society for Information Display (SID) 2002 International Symposium. The four-hour course was attended by over 200 people on a Sunday evening from 6 pm to 10 pm. Emphasis was placed on: (1) techniques being as important as good equipment, and (2) reflection metrology is more complicated than currently envisioned by the display industry.

FY Outputs

Collaborations

In addition to the collaborations that follow naturally from standards activities (see below) and other routine advisory roles, there are some specific collaborations of interest that are currently underway:

We are working with the Food and Drug Administration (FDA) on making small-area measurements of radiological images using stray-light-reducing probes for small-area measurements of luminance.

Robust and meaningful reflection measurements of reflective displays are being developed in collaboration with ISO and EIA standards activities.

Standards Committee Participation

VESA (Video Electronic Standards Association) Display Metrology Committee: E. F. Kelley used to chair this committee, which produced the Flat Panel Display Measurement (FPDM) Standard, a scientific and comprehensive document, prepared with significant input from NIST, to address display metrology. Kelley now serves as its editor and is in the process of generating all the patterns used by the standard.

ISO TC159/SC4/WG2 Visual Display Requirements: P. A. Boynton is a member of this committee, which is developing a revision of all of its display standards. NIST is coordinating the development and evaluation of the metrology sections. (ISO, International Organization for Standardization)

ANSI & PIMA IT7-3 Electronic Projection: P. A. Boynton is a member. The IT7-3 is presently evaluating and revising present ANSI/PIMA projection standards for the future revision. (ANSI, American National Standards Institute; PIMA, Photographic & Imaging Manufacturers Association)

SAE J 1757 Standard Metrology for Vehicular Flat Panel Displays: E. F. Kelley is a member and is providing support in the evaluation of reflection measurement standards. (SAE, Society for Automotive Engineers)

CORM CR-5 (Flat Panel Displays). All project personnel are members. J. M. Libert is working with the committee to evaluate the DMATS and GAS program. (CORM, Council for Optical Radiation Measurements)

CIE TC2-42 Colorimetric Measurements for Visual Displays. P. A. Boynton is a member. The committee is preparing a recommended practice for display colorimetry metrology. (CIE, International Commission on Illumination)

Recent Publications

P.A. Boynton, "Evaluation of a Liquid-Filled Camera for Measurement of Shadow Detail. Part I: Sensor Evaluation," NIST IR 6900, August 2002.

J.M. Libert, E.F. Kelley, P.A. Boynton, S.W. Brown, C. Wall, and C. Campbell, "A Color Gamut Assessment Standard: Construction, Characterization and Inter-Laboratory Measurement Comparison," Fourth CORM Oxford Conference on Spectrometry," Davidson, NC, June 9–13, 2002. In review.

P.A. Boynton, E.F. Kelley, and J.M. Libert, "Current Projects in Display Metrology at the NIST Flat Panel Display Laboratory," Fourth CORM Oxford Conference on Spectrometry," Davidson, NC, June 9–13, 2002. In review.

Edward F. Kelley and Aldo Badano, "Characterization of Luminance Probe for Accurate Contrast Measurements in Medical Displays," NISTIR (National Institute of Standards and Technology Interagency Report) 15 pages, 2002. In review.

E.F. Kelley, "Fundamentals of Display Metrology," 2002 Society for Information Display International Symposium Short Course S-3, 2002 SID International Symposium, Boston, Massachusetts, 205 pp., May 19–24, 2002.

E.F. Kelley, "Sensitivity of Display Reflection Measurements to Apparatus Geometry," 2002-SID International Symposium Digest of Technical Papers, Society for Information Display, Boston, MA,, pp. 140-143, May 19–24, 2002.

"The work you're doing with flat panel display measurement is extremely important to the display industry and especially the aviation community where we are driven as much by safety as perceived quality and cost."

Alan Jacobsen
Technical Fellow
Boeing

P.A. Boynton and E.F. Kelley, "NIST Stray Light Elimination Tube Prototype," NISTIR 6861, March 2002.

P.A. Boynton and E.F. Kelley, "Stray Light Compensation in Small Area Contrast Measurements of Projection Displays," Projection Displays VIII, Proceedings of the SPIE, Vol. 4657, pp. 122-130 (January 2002).

E.F. Kelley, "Vehicular Display Metrology Seminar," Society for Information Display Metropolitan Detroit Chapter, 8th Annual SID Symposium on Vehicle Displays, Detroit, MI, October 16-18, 2001.

E.F. Kelley, "SAE J1757 Committee Report on Proposed Reflection Measurements," 8th Annual SID Symposium on Vehicle Displays, October 16–18, 2001.

Infrastructure for Integrated Electronic Design & Manufacturing

Project Goals

To actively contribute to the technical development of neutral product data exchange specifications, manufacturing specifications, and component information infrastructure for the electronics industry. The project focuses its efforts on two areas: Electronic Commerce of Component Information (ECCI) and Internet Commerce for Manufacturing (ICM). The ECCI staff work with industry and other government laboratories to promote the transfer of technical information and computer models between Original Equipment Manufacturers (OEMs), electronic parts manufacturers, and those who need parts for the design, manufacture, and repair of electronic systems. The ICM staff focuses on providing an environment in which small manufacturers of mechanical and electronic components may participate competitively in virtual enterprises that manufacture printed circuit assemblies (PCA).

Ya-Shian Li evaluates a LART board that was produced using the GenCam standard.

In particular, ICM is working to identify and overcome some of the manufacturing information technology problems that exist at the intersection of manufacturing and electronic commerce.

Customer Needs

To maintain a globally competitive posture, electronics manufacturers are quickening their pace of production and innovation. Electronic products are transitioned rapidly to a commodity status, production sites are constructed and decommissioned in shorter timeframes, and manufacturers are globally outsourcing an expanding scope of production processes – and in some cases, the entire design and production process. To achieve the flexibility and quick turn-around they require, manufactures rely on a distributed supply network and the ability to "mix and match" hardware and software within their own enterprises. This rapid reconfigurability needed by industry depends upon a robust IT infrastructure, consisting of standards for collaboration, business process integration and the exchange of technical data. Industry also needs neutral test beds in which to evaluate new standards and the risks associated with technology adoption.

Technical Strategy

This project is working with industry to enable the infrastructure needed to support electronic commerce for both electronic components and manufacturing. For ECCI, the technical areas being addressed are: the fundamental terminology used to describe components, the organization of the component data and metadata, and the ability to access this data and incorporate it into the life cycle of a design specification. Development of standards within this domain is crucial in order for U.S. electronics manufacturers to take advantage of the global marketplace. This project assists industry in the development of standards that are crucial to the infrastructure, but that no single company will pursue because of the broad-based benefit. Industry and standards groups in both Japan and Europe are actively working on ECCI related projects. In working with these groups NIST will try to minimize overlapping standards development and to ensure interoperability between U.S. and international ECCI standards.

DELIVERABLES: By 2004, finish the international interoperability testing of electronic component information exchange being performed between RosettaNet (USA), ECALS (Japan), MERCI (Europe), and others. Publish the final results to both U.S. industry and major standards organizations.

One key aspect of this work, as identified by industry, is the need for on-line traceable dictionaries in order to effectively distribute electronic component data via the Internet. On-line dictionaries enable the industry to properly evaluate electronic component information. In support of on-line

Technical Contact:
John Messina

Staff-Years:
4.5 Professionals
1.0 Guest Researcher
1.0 Student

"The DictionaryBuilder is an ongoing open-source development project, being developed by RosettaNet and PTC, with assistance from Si2 and NIST."

RosettaNet announcement

dictionaries, NIST has been working with large industry consortiums, such as RosettaNet and Si2, providing technical expertise in the design of both the electronic dictionary formats and the software tools necessary to access and use those newly created dictionaries.

While the project's original work on dictionary tools focused on designing tools that would facilitate the use of the on-line dictionaries, it soon became evident that industry needs additional software tools. Based on the experience of RosettaNet and their dictionary maintenance concerns, NIST adapted its on-line dictionary toolkit software tools in order to add support for dictionary creation and maintenance. A more generic dictionary toolset built around the common dictionary format could easily be adapted to support new areas of PCB manufacturing that have not already developed their own dictionaries of components and even into other areas of electronics such as semiconductors.

DELIVERABLES: By 2005, build a generic dictionary builder and maintenance software application based on existing NIST tools and the common dictionary format. Use this new toolset to help industry build new dictionaries compatible with existing dictionary work.

The project has also established the ICM Testbed in order to validate new technology and demonstrate to industry the use and benefits of new standards. Working with industry, NIST has been identifying needs in a variety of business scenarios involving Printed Circuit Board (PCB) manufacturing and assembly. These business scenarios are being used to help design a web-based portal Trading Portal system using custom NIST developed and acquired commercial software components. The Trading Portal then serves as a demonstration tool that allows industry to see how newly developed standards would work in real world business scenarios and allows industry to analyze the risks involved with adopting new standards.

The ICM focus is also part of a multi-laboratory effort at NIST to support the manufacturing industry. As a member of the National Advanced Manufacturing Testbed (NAMT), the team has the opportunity and responsibility to make our results widely known. The team participates in a variety of in-house demonstrations and internal seminars, as well as conference demonstrations in collaboration with IPC, National Electronics Manufacturing Initiative (NEMI), and RosettaNet. The manufacturer's business case, standards roadmaps, and proceedings from all workshops are published and disseminated through the project website. The ICM testbed is now also a part of an NIST Advanced Technology Program (ATP) intramural project linking several other NIST based testbeds into the new common Semantic Interoperability Testbed.

DELIVERABLES: By 2003, advance the web-based B2B Portal project to be able to support complete round trip business transactions between board buyer, manufacturers, and electronic component suppliers using open standards.

Accomplishments

- NIST participated in an International Dictionary Mapping Experiment with participants from ECALS, RosettaNet, MERCI to study the differences between the electronic component dictionary formats promoted by the three organizations.

John Messina (left) participates in a 2002 IEC TC93 meeting in Austin, Texas.

- John Messina chaired and directed two IEC international working groups within Technical Committee (TC) 93: Library of Reusable Components (WG6) and Test, Validation, Conformance and Qualification Technologies (WG5).

- IIEDM staff initiated work on a new web-based Trading Partner Portal created to demonstrate how new standards can be applied to existing business scenarios in printed circuit board manufacturing: 1) Developed an initial test configuration for the Web Portal Project including establishing basic infrastructure components, key emerging technical standards, and several test scenarios, 2) Designed, implemented, and tested messaging software designed to transport board design information in RosettaNet PIP formats, and 3) Explored methods of PIP validation using combinations of XML Schema, XSLT, and program code to enforce standard value constraints and valid relationships among data elements.

- NIST continues to provide technical support for Si2's QuickData dictionary format (now RosettaNet's Technical Dictionary), and development of reference implementation software: 1) NIST's Query Generator toolkit was updated to reflect the newest version of RosettaNet's RNTD and PIP2A9 specifications in its electronic components queries and responses, and 2) The reference implementation toolkit was provided to members of the international dictionary experiment as an aid to generating RosettaNet PIP2A9 queries for use in the dictionary testing.

- Through co-leading committees within IPC and NEMI, project staff helped produce 16 published IPC standards, 3 proposed IPC standards, and over a dozen RosettaNet specifications for the transfer of manufacturing data across the electronics supply chain.

- The IIEDM Project collaborated with ITL on the design and development of the proposed new Financial Action Secure Transaction (FAST) protocol for establishing business relationships between unknown partners using existing relationships with banks as trusted parties.

- The IIEDM Project continued its industrial project collaboration with the French university ESIAL. As part of the project, the project staff directed a team of 4 students in the development of several key pieces of software that were later incorporated into the Web Portal Project.

FY Outputs

Collaborations

We are working with RosettaNet, IEC, MERCI, and ECALS in an international dictionary mapping experiment that is looking at the differences between the electronic dictionary formats promoted separately by the three groups.

We are working with the Institute for the Packaging of Electronic Circuits (IPC) by providing technical expertise and co-leading the development of several of the IPC 25XX series of standards.

Within NIST, this project is part of a new interlaboratory project ATP project with the Information Technology Laboratory, the Manufacturing Engineering Laboratory, the Building Fire Research Laboratory, and the Manufacturing Extension Partnership Laboratory linking together multiple software testbeds into a new Semantic Interoperability Testbed.

We worked with NEMI on the development of the FY2002 Technology Roadmap document by co-leading to the Product Lifecycle Information Management (PLIM) working group.

We are working with Semiconductor Equipment Materials International (SEMI) on new semiconductor standards initiatives by providing insight from other industries such as Electronic Design Automation (EDA) with similar data exchange complexities.

Standards Committee Participation

IEC/TC93/WG5 Test Validation, Conformance and Qualification for Standards: John Messina is convener of IEC/TC93/WG5, which is the working group responsible for defining methodologies and/or guidelines for the conformance and certification testing of any product which implements a TC93 standard.

IEC/TC93/WG6 Libraries of Reusable Parts for Electrotechnical Products: John Messina is co-convener, working on standards and infrastructure necessary to support the exchange of component information at the international level.

IPC 2-17: John Messina is a member of the IPC 2-17 committee which is involved in merging the ODB++ and GenCAM standards.

IPC 2-15: Barbara Goldstein chairs the IPC committees 2-15 and 2-15a, which creates and maintains the PDX standards for supply chain communication.

RosettaNet: John Messina, Kevin Brady, and Michael McCaleb have been working with RosettaNet to develop and evaluate technical standards for B2B E-commerce transactions for electronic components, and technical dictionaries for describing electronic components.

International Technology Roadmap for Semiconductors (ITRS): Ya-Shian Li and Barbara Goldstein are currently participating in industry roadmapping efforts mainly for the ITRS Design and Factory Integration (FI) Technical Working Group (TWG). Barbara is leading the Engineering Chain Management subteam.

Recent Publications

J.V. Messina, "RosettaNet DictionaryBuilder Maintenance System Software," National Institute of Standards and Technology. (U.S.), December 2001.

J.V. Messina, M.R. McCaleb, “Query Generator Software,” National Institute of Standards & Technology. (U.S.), June 2001. Design and Automation Conference (DAC) release.

J.V. Messina, M.R. McCaleb, “QuickData Generator – Virtual Components (VC) Software, “National Institute of Standards & Technology. (U.S.) December 2000. Design Automation and Test in Europe (DATE) release.

Knowledge Facilitation

Goals

■ To eliminate paper-intensive and manual operations by automating tasks, decreasing the administrative requirements of the technical and support staff, increasing responsiveness to customers, and implementing a secure eNIST paperless environment.

■ To provide Information Technology security policies, procedures, guidelines, and baselines and ensure compliance with Government Information Security Reform Act (GISRA) requirements.

■ To develop and refine a workflow application to enable the automatic tracking of technical and administrative calibration information. This tracking system, the Information System to Support Calibrations (ISSC), reduces the percentage of time NIST scientists and support staff spend on producing the necessary calibration forms and associated reports.

June Sims closes a test folder with the ISSC. The ISSC is used to warehouse technical calibration data and generate Reports of Calibration.

Customer Needs

The ISSC continues to eliminate the paper-intensive and manual processes involved with calibrations performed at NIST. The ISSC automates processes and decreases the administrative requirements of the technical and support staff. Income, workflow information, and mechanisms to report current income and projecting future income are readily available to management. ISSC staff continue to look for ways to improve the total experience of the customer along with decreasing the turn around time of the calibration process.

Providing calibration customers information electronically is an on-going goal. As security mechanisms are implemented in web browsers (e.g., digital signatures), we will be able to provide customers with access to calibration data, calibration reports, and other information on-line.

Web-based applications have been created to store and track all of the Electronics and Electrical Engineering Laboratory (EEEL) publications and reports provided to management. Management is able to easily obtain access to the information they need, and the administrative burden on the technical staff has been alleviated. The applications also serve as a warehouse for all publications and reports.

A web-based information system was developed for Conference Facilities' use that automates all the processes of conferences from registration to billing.

A web information system was created to log and track all paper documents so the status of required paperwork can be easily determined.

Technical Strategy

The ISSC is a structured-query language database-driven application. The ISSC stores all of the administrative, technical, and financial data involved with items calibrated at NIST. The system has over 250 NIST users and provides status information to over 1400 calibration customers. The web-based system allows access from an unlimited number of different machines and operating systems used by personnel at NIST. The ISSC has reduced the time to complete the required paperwork by automating the entire workflow process.

A custom interface has been developed for the Calibration Program (a central calibration coordination office) to monitor and assist in the administrative aspects of the calibration process. The Chief Financial Officer's personnel have been provided access to generate the required billing information and print customer invoices directly from the system.

Each of the twelve divisions at NIST that performs calibrations has been given access to the ISSC. User's access is controlled and separated by job functions: administrative, technical, and data entry.

The ISSC was developed in EEEL. Maintenance and future development of the ISSC has been transitioned to Technology Services (TS) so the

Technical Contact:
Jennifer A. Lindeman

Staff-Years:
1.0 Professional
2.0 Students

"This is great! We no longer have to interrupt the NIST Tech with 'Is it done, yet?' questions. Quick, easy, and we don't bother the NIST technician."

Robert M. Graham
Primary Calibration Lab
Sandia National Laboratories

ISSC does not reside in a technical Laboratory. EEEL staff act as consultants to TS.

DELIVERABLES: By 2004, finish transition of the development and maintenance of the ISSC to Technology Services.

One feature of the ISSC is the ability to produce a calibration report based on the calibration data entered and stored in the ISSC. This provides a standard format for reports across all the NIST divisions, helping to develop a standard method and format for reporting calibration results.

The ISSC also generates a cover letter for technical reports.

DELIVERABLES: By 2005, provide the capability to allow detailed technical Reports of Calibration to be generated by every division.

A committee was formed to provide an input mechanism for the technical staff into the development and enhancements to the ISSC. The Information System to Support Calibrations Oversight Committee (ISSCOC) is comprised of a representative from each calibration division, the Information Technology Laboratory, the Calibration Program, and the office of the Chief Financial Officer. The committee meets bi-monthly to resolve problems encountered with the software and to determine enhancements to the software.

The ISSC generates all of the paperwork required with calibrations; such as letters to the customer, standard forms, and even mailing labels. Multiple financial and turn-around-time reports can be instantly generated from the ISSC.

DELIVERABLES: By 2004, add extensive reporting capabilities to allow users to build ad hoc, custom reports.

The ISSC warns technicians as deadlines approach and notifies management if deadlines are missed. This has improved turn-around-time, forced technicians to generate sensible estimated completion dates, and ensured items do not fall in between the cracks, thus increasing customer satisfaction.

Access to the status of a calibration while a device is in for calibration is given to customers who desire this kind of real-time information. The access is secure, using web-based security mechanisms, so the customer is the only one with access to their information. As security is enhanced, we will be able to provide more information electronically (e.g., electronically provide a Report of Calibration).

DELIVERABLES: By 2003, investigate incorporation of the ISSC with the Security and Access Control (SAC) project for single sign-on and role-based access control.

DELIVERABLES: By 2003, implement increased security using Secure Socket Layers (SSL) technology for NIST users.

DELIVERABLES: By 2003, implement reporting tools for the information system for publications.

Accomplishments

- ISSC has been deployed NIST-wide to 12 Divisions, the CFO's office, and the Calibration Program, with little-to-no interruption in day-to-day activities. All calibration personnel at both the Boulder and Gaithersburg NIST campuses now use the ISSC. A new system did not need to be procured by NIST, which saved dollars and the time that would have been required to develop and integrate a new customized calibration system. Communication between Boulder and Gaithersburg is nearly seamless, and the web-based system allows Gaithersburg staff to assist Boulder in day-to-day calibration administrative operations.

- Kevin Brady, Jennifer Lindeman, and John Messina received the Department of Commerce Bronze Medal Award for their work with the ISSC.

- Technical and customer support has been provided to over 250 users. ISSC Training classes have been held for the technical, data entry, and administrative areas. Online tutorials are available.

- ISSCOC committee has been a success. The ISSCOC has given the NIST technical staff the vehicle they needed to provide input into the development and improvement process of the ISSC. The committee meets bi-monthly to gather requirements from a representative of each calibration division using the ISSC. The committee has also provided an excellent forum for the exchange of calibration questions not related to the ISSC.

- Customer access pages have been implemented for every calibration done at NIST. Every NIST customer who sends in an item to be calibrated can now check the status via a secure web page. A Secure Socket Layer (SSL) implementation has been put in place to provide security, and the pages are updated nightly with status information. A customer survey and comments page is also available for customers to provide feedback on the calibration process at NIST.

ISSC development team awarded the NIST bronze medal, Kevin Brady, John Messina and Jennifer Lindeman.

FY Outputs

Collaborations

We are working with Technology Services to ensure the transition of the development and maintenance of the ISSC to their control is successful and invisible to ISSC users.

Recent Publications

K. G. Brady, "An Information System to Support Calibration," NISTIR 6425, Natl. Inst. Stand. Technol. (U.S.), December 1999.

Electricity Division Staff Recognition

Edward F. Kelley

The William P. Slichter Award

"… for the development of standards for flat panel display measurements and forging new interactions with U.S. industry"

Certificate of Appreciation from the Society for Information Display

"… for his continuous support of SID and SAE activities and for educating engineers and promoting proper optical metrology"

Kevin Brady, John Messina, and Jennifer Lindeman

Department of Commerce Bronze Medal

"… for their work in developing the Information System to Support Calibrations (ISSC) and in promoting its use by all NIST calibration services"

Kevin G. Brady

EEEL Diversity Award

"… for his work in recruiting and supervising a diverse group of college and high school students, and creating an environment where they learn from each other and gain valuable work experience"

David B. Newell

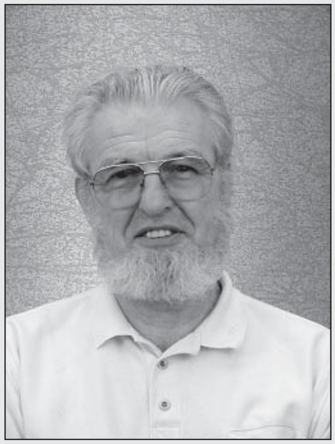
EEEL Diversity Award
"… for securing funding for and implementing a Summer Undergraduate Research Fellowship (SURF) program within EEEL, on his own initiative"

Kenneth L. Stricklett

IEEE Industrial Applications Society Working Group Award
"… for the revision of IEEE Standard 114, "Standard Test Procedure for Single-Phase Induction Motors"

John M. Libert

Certificate of Merit from The Society of Motion Picture and Television Engineers
"… for outstanding achievement in the motion imaging industry"



Francois D. Martzloff

Working Group Recognition Award
IEEE Power Engineering Society
"… for contributions to the development of C62.41.1, C62.41.2, and C62.45" [three IEEE standards on applications of surge-protective devices]

Joseph R. Kinard, Jr.

Thomas E. Lipe, Jr.

Algie Lance
Best Paper Award

2001 Measurement Science Conference

Neil M. Zimmerman

2000 Edward Uhler Condon Award

(with Ali Eichenberger, Mark W. Keller, and John M. Martinis, Div. 814)

ELECTRICITY DIVISION CALIBRATION SERVICES

The Electricity Division provides a number of for-fee calibration services of electrical standards. Below is an abbreviated listing of those services. More information, including a fee schedule can be found in the NIST Calibration Services Users Guide SP250 available from the Calibration Program at NIST, (301)-975-2002, calibrations@nist.gov, or on the Web at: http://ts.nist.gov/ (click on "Calibrations," then "Electromagnetic").

Information about the availability and shipping requirements for the Electricity Division services listed below may be obtained by contacting Denise D. Prather, (301) 975-4221, denise.prather@nist.gov. Technical information may be obtained by contacting the specific technical representatives listed below for each service.

A. Resistance Measurements

A.1	DC Resistance Standards and Measurements	Randolph E. Elmquist (301) 975-6591 George R. Jones (301) 975-4225
A.2	High-Voltage Standard Resistors	Kenneth L. Stricklett (301) 975-3955 Gerald J. FitzPatrick (301) 975-2737

B. Impedance Measurements (Except Resistors)

B.1	Low-Frequency Capacitance and Inductance Measurements and Standards	Andrew D. Koffman (301) 975-4518 Yicheng Wang (301) 975-4278
B.3	Power-Frequency Capacitors	Eric D. Simmon (301) 975-3956 Gerald J. Fitzpatrick (301) 975-2737

C. Voltage Measurements

C.1	DC Voltage Measurements and Standards	June E. Sims (301) 975-4238 Yi-hua Tang (301) 975-4691
C.2	AC Voltage Measurements	Mark E. Parker (301) 975-2413 Nile M. Oldham (301) 975-2408
C.3	AC-DC Thermal Voltage and Current Converters (to 1 MHz)	Thomas E. Lipe (301) 975-4251 Joseph R. Kinard (301) 975-4250

D. Precision Ratio Measurements

D.1 Inductive Dividers .... Andrew D. Koffman (301) 975-4518
Kenneth L. Stricklett (301) 975-3855

D.2 Resistive Dividers .... Kenneth L. Stricklett (301) 975-3955
Gerald J. FitzPatrick (301) 975-2737

D.3 Capacitive Dividers .... Gerald J. FitzPatrick (301) 975-2737
James A. Pitt (301) 975-2417

D.4 Mixed Dividers .... Gerald J. FitzPatrick (301) 975-2737
James A. Pitt (301) 975-2417

D.5 Voltage and Current Transformers .... Eric D. Simmon (301) 975-3956
Thomas L Nelson (301) 975-2986

E. Phase Meters and Standards and .... Mark E. Parker (301) 975-2413
VOR Measurements ....Nile M. Oldham (301) 975-2408

F. Power and Energy Measurements, ... Thomas L Nelson (301) 975-2986
Low-Frequency .... Joseph W. Chandler (301) 975-2868

I. Pulse Waveform Measurements .... Donald R. Larson (301) 975-2437
Nicholas G. Paulter (301) 975-2405

Post-Doctoral Research Associateships

The Electricity Division at the National Institute of Standards and Technology (NIST), in cooperation with the National Research Center (NRC), offers awards for postdoctoral research for American citizens in the fields described below. The Division conducts research in fundamental electrical metrology, mixed signal testing strategies, power and energy metrology, and metrology to support digital video and video display characterization to provide, through both experimental and theoretical work, the necessary basis for solving the measurement-related requirements of the electronics and electrical-equipment industries.

NIST affords great freedom and an opportunity for both interdisciplinary research and research in well-defined disciplines. These technical activities of NIST are conducted in its laboratories, which are based in Gaithersburg, a large complex of modern laboratory buildings in a Maryland suburb of metropolitan Washington, DC. Although applications for NIST Research Associateships are accepted throughout the year, they are evaluated by the panels only during February. Additional information can be found at the NRC Research Associateships Program website: http://nationalacademies.org/ (click on Fellowship & Postdoc Opportunities and then Research Associateship Programs).

High-Speed Signal Acquisition

Contact: Barry A. Bell

As part of a metrology program to meet the need for improved signal acquisition and processing systems, NIST researchers are developing theoretical models, experimental methods, and standards for waveform metrology of conducted signals. This theoretical and experimental research is applied to the development of standards for high-speed A/D converters and waveform recorders operating at signal frequencies up to 5 GHz. Theoretical aspects of the work include Fourier analysis, deconvolution techniques, and time-domain analysis, while the experimental part of the program includes work in precision pulse generation, static and dynamic testing, and programming for hardware control in assembly and higher level languages.

Synthesized Waveform Standards

Contact: Barry A. Bell

Theoretical and experimental research is being conducted in synthesizing precision alternating current (ac) waveforms for use in AC voltage and arbitrary waveform standards operating nominally below 100 MHz. Theoretical work includes the use of Walsh and triangular functions as the basis for improved waveform fidelity, while experimental work involves high-speed, high-accuracy digital-to-analog conversion; precision, high-speed switching; assembly and higher level language programming for hardware control; and wideband, fast-settling amplifiers.

Testing Electronic Systems

Contact: Barry A. Bell

New strategies are needed to evaluate the performance of complex electronic circuits, devices, and instruments using the fewest possible tests. The testing strategies program in progress includes theoretical studies in modeling of nonlinear systems, optimization techniques using linear matrix methods, statistical and random processes, and neural networks. In addition, experimental work addresses strategies for component and instrument testing, fault diagnosis, functional testing, and calibration. Desktop computers, workstations, and supercomputers are available for computer simulation and analysis.

Picosecond Electrical Pulse Metrology

Contact: Barry A. Bell

Theoretical and experimental research opportunities exist to study different problems related to picosecond electrical pulse metrology. These problems generally fall into one of three categories: fast pulse generation, with a goal of creating better pulse generator standards; fast pulse transmission, with goals of characterizing and understanding various transmission line structures from a time domain perspective; and fast pulse measurement, with goals of developing faster, more accurate and more robust pulse measurement systems. Most of these problems also offer opportunities to study signal processing as it relates to discrete, time domain measurement systems. Research facilities include several automated, fast electrical pulse sampling systems, and fast-pulse laser systems useful for electro-optic sampling, photoconductive switch pulse generation, and other experiments.

AC-DC Measurements and Standards

Contact: Barry A. Bell

This research area provides US industry with the link between the DC and corresponding AC electrical standards by improving and maintaining the US national standards of AC-DC difference, which are used to provide calibrations and measurement services for thermal voltage converters and current shunts. We are developing a new capability for calibrating high current (100 A) shunts and high voltage (500 V to 1000 V) thermal converters. More reliable semiconductor thin-film converter devices are also being developed that can be readily fabricated and have state-of-the-art AC-DC differences. A new national primary standard is also being developed to support measurement uncertainties at the 0.1-microvolt per volt level.

Precision Measurements of AC and Pulsed Currents and Voltages

Contact: Gerald J. FitzPatrick

Because of their immunity to electromagnetic interference, optical sensors based on the electro-optic Pockels' and Kerr effects and on the magneto-optic Faraday effect are advantageous for measuring high voltages and currents. These sensors are now being employed by the electric power industry in diagnostics, metering, and protection applications. They have been used for diagnostics in large pulse-power machines such as radiation simulators and electromagnetic launchers. Our research goals are to develop and evaluate the performance of electrical measurement systems and to develop techniques to ensure their long-term reliability. We are evaluating the response of sensors to steady-state signals and submicrosecond pulses, and assessing measurement uncertainties in well-characterized systems, such as high voltage dividers, Rogowski coils, and derivative (E-dot and B-dot) sensors. For AC measurements, new circuit designs are being developed for active high-voltage dividers with improved stability and reduced measurement uncertainties. In addition, experiments and mathematical models are used to characterize the dependence of the electrical and optical properties of optical sensor materials on environmental parameters (e.g., temperature, pressure, and radiation). Finally, numerical techniques are developed and applied to identify the sources and magnitudes of measurement errors and to compensate for them.

Fundamental Constants, Precision Measurements, and Electrical Units

Contact: Edwin R. Williams

The Division is engaged in research on methods to improve accuracies of fundamental physical constants and to develop better and more accurate techniques for measuring and maintaining basic electric units. Research includes developing nuclear magnetic resonance-based current and voltage standards and measurements of the proton gyromagnetic ratio, absolute ampere, absolute volt, absolute farad and ohm, quantized-Hall resistance, and fine-structure constant. We are particularly interested in refining our current techniques and/or initiating new experiments to increase knowledge of these quantities or other constants of comparable importance, especially those involving the electrical units.

"Electronic Kilogram"– The SI Determination of the Ratio of the Mechanical Watt to the Electrical Watt

Contact: Richard L. Steiner, Edwin R. Williams

Our goal is to accurately define the electrical Watt as determined from Josephson Volt and Quantum Hall Ohm in terms of their SI definitions, which are related to the Kilogram, Second, and Meter. This experiment uses an ampere balance and has the potential to electronically monitor the Kilogram, which is the last artifact standard and may not be a true constant, and also to determine Planck's constant and the mass of the electron. To perform this difficult and timely experiment, scientists are needed with experience in precision measurements of force and mass (balance design), velocity and position (optical interferometry), and voltage and current (magnetics and induction coils) to 0.01 ppm uncertainty. A good understanding of classical electromagnetics, mechanics, and optics is necessary, and experience with electromagnetic interference protection, vibration isolation, and instrumentation programming would be useful.

Single Electron Effects

Contact: Neil M. Zimmerman

In nanoscale electronic circuits, we can observe Coulomb blockade or single electron tunneling (SET) effects. For metrological applications, the basic device is the single electron pump, which allows control of electrical flow in units of 1 e. This device enables accurate measurements of electrical current or charge. The Electricity Division studies such effects and their implications for precision metrology of the electrical units. We are pursuing two goals, both in close collaboration with our Boulder location. The first involves using the electron pump to charge up a cryogenic capacitor. Then, by comparison to the Calculable Capacitor and Josephson Volt experiments, we will make metrological measurements of the electrical charge, e, or the fine structure constant, α. Our second goal is to investigate ways to increase the value of the current, for use as a direct current standard. Our current approach is to use Si-based SET pumps, which hold the potential to be parallelized.

Quantum Computing Using Single-Electron Tunneling Devices

Contact: Neil M. Zimmerman

The use of quantum coherence for computing has gathered a lot of attention in the past few years, since it was shown that some computing algorithms can be vastly sped up using quantum computers (QC). One type of device envisioned for QC is that based on single-electron tunneling (SET) devices in the superconducting state, where the quantum computer "qubit" is the presence or absence of one extra pair of electrons. We are studying such an application in collaboration with a number of groups, including the University of Maryland and

SUNY Stonybrook. One of our interests is in the problem of the charge offset and noise, which limit any possible use in QC. In addition, we are interested in the use of Si-based SET devices for detection of single spins, which form the basis for another possible QC qubit.

Physics of Josephson Junctions at Microwave Frequencies and Precision Voltage Measurement

Contact: Richard L. Steiner

The physics of Josephson junctions, driven at microwave or millimeter wave frequencies, has important applications to ultrahigh precision voltage measurements. Among the behaviors observed but not well understood are complex frequency responses of series-array Josephson junctions at frequencies between 70-95 GHz, variable stability of quantized voltage steps in these devices, and the generation of Shapiro voltage steps at fractional values in series arrays. Related applications in voltage measurement include the characterization of noise in electronic instrumentation, especially Zener-diode based references, at submicrovolt levels for normal measurement frequencies (>10 mHz), and nonlinear noise for much lower frequencies (>1 μHz).

Research facilities include several Josephson array voltage calibration stations, temperature and humidity test chamber, phase-locking millimeter wave sources (70-95 GHz), a high-resolution spectrum analyzer, power meters, an assortment of high-precision voltage and frequency measurement and reference instrumentation, and various waveguide-equipped probes and magnetically shielded Dewars for cryogenic measurements.

Resistance Comparisons for Fundamental Electrical Standards

Contact: Randolph E. Elmquist

Converting single-electron tunneling (SET) devices into next-generation usable precision electronic will require precise cryogenic current-multiplication and a better understanding of highly resistive thin films. Our work would be aided by fabrication of improved thin-film resistance-material devices and studies of mesoscopic processes contributing to resistive noise at low temperature. This research would contribute to development of a precision three-way comparison of the SET current, lead to better measurements of Planck's constant, and improve the uncertainty of precision SET-based current sources.

Quantum Hall Effect

Contact: Marvin E. Cage,
Randolph E. Elmquist

The Electricity Division is involved in a continuing research program on the quantum Hall effect, with emphasis placed on using it to maintain the US legal unit of resistance and to determine the fine structure constant to the highest possible accuracy. Any experiments that would further the understanding of the quantum Hall effect or explore its limitations would be of interest. Such experiments could include temperature and current dependence, current distribution (edge and bulk effects), voltage quantization (breakdown effect), and AC quantized Hall resistance measurements that lead to AC impedance standards. Theoretical studies are also needed in all of these areas.

The apparatus consists of two 16-T persistent-current superconducting magnets, a top-loading He-3 refrigerator, a variable temperature insert, and automated quantized Hall resistance measurement systems with parts-per-billion uncertainties.

In support of this research, a clean-room sample preparation facility has been installed that is equipped with a micrometer photo-mask aligner, wire bonder, annealing oven, and probe test station as required for the definition, mounting, ohmic contacting, and room-temperature testing of semiconductor samples for quantum Hall experiments.

Quantized Hall Resistor Fabrication and Research

Contact: Kevin C. Lee

National Standards Laboratories around the world use quantized Hall resistors to maintain their resistance standards. However, too little is known about the physical principles affecting their operation and the mechanisms responsible for their degradation. Furthermore, there are no reliable or repeatable techniques for fabricating devices of standards quality. Research in this area spans the fields of chemistry, materials, and physics. This program centers on (1) furthering the understanding of the physical principles that influence device performance under typical operating conditions; (2) developing techniques to fabricate reliable, standards-quality quantized Hall resistors; and (3) extending the range of operation of these devices to higher temperatures, lower magnetic fields, and higher currents. Sample preparation facilities include a clean room with equipment for optical photolithography, a wire bonder, an alloying furnace, and thin-film deposition. Research facilities include a cryostat with a superconducting magnet capable of testing samples at temperatures as low as 1.1 K in fields up to 16 T and an automated digital voltmeter-based measurement system capable of uncertainties as low as 0.05 ppm.

Capacitance Standards and AC Measurements

Contact: Yicheng Wang

The Electricity Division ties the US legal system of electrical units for capacitance, inductance, and resistance to the SI system of units. First, we realize the SI farad from the SI meter through the calculable capacitor whose capacitance depends on only one length. We then realize the SI henry from a Maxwell-Wien bridge and the SI ohm from a quadrature bridge. However, routine calibrations demanded by the evolving industry call for research beyond these classical experiments used for the realization of the electrical units. Current research focuses on the frequency dependence, in the audio frequency range from 50 Hz to 20 kHz, of capacitance standards including the calculable capacitor, toroidal cross capacitors, and fused-silica capacitors. In close collaboration with other staff, we are also pursuing two alternative representations of the farad: (1) an AC Quantum Hall Resistor with a quadrature bridge and (2) a single electron pump with a cryogenic capacitor. To fully take advantage of these quantum effects, classical precision AC bridge methods must be re-examined and automated whenever possible.

Capacitance Standards and Measurement Research

Contact: Yicheng Wang

This work ties the US legal system of units for capacitance and resistance to the SI system of units. This is done through the calculable capacitor experiment that can also be used to determine a value for the fine structure constant by comparison with the quantized Hall resistance. This determination of the fine structure constant currently has an uncertainty of 2 in 10^8, which is the lowest in the world for this method. Work is in progress to further reduce the uncertainty of this determination. Other research in this area involves the development of precision AC transformer bridges for capacitance and resistance measurements with uncertainties of a few parts in 10^9. The techniques for building these bridges have been developed at NIST for scaling of resistance and impedance measurements of the highest levels of accuracy. Current efforts include extending these bridge measurements from 1,592 Hz, which is currently used, to frequencies between 100 Hz to 2,000 Hz. These AC bridges will also be used in the AC quantum Hall experiment and the single electron tunneling experiment.

Flat Panel Display Metrology

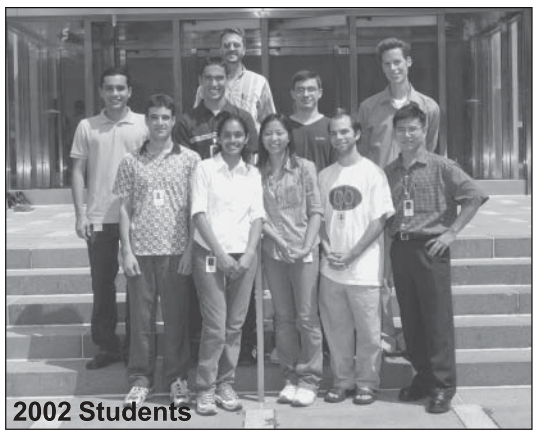
Contact: Edward F. Kelley

NIST's flat panel display laboratory serves the display industry by developing and quantifying good electronic display metrology for industrial use. With the explosion of the information age, the Internet, and e-commerce, the use of flat panel displays has become a growing need for US industries. Good display measurement methods are needed because of the fierce competition between technologies, allowing consumers to compare features of displays accurately and fairly. NIST is doing research in: (1) equipment on improving measurements made on displays; (2) development of display metrology with various standards organizations; (3) development of display metrology assessment methods and equipment to provide guidance for the implementation of good measurement methods in the display industry; and (4) display reflectance characterization, measurements, and modeling using the bi-directional reflectance distribution function.

SURFing the Electronics and Electrical Engineering Laboratory

The Electronics and Electrical Engineering Laboratory at the National Institute of Standards and Technology offers a 12-week Summer Undergraduate Research Fellowship Program (SURF) in conjunction with the other successful SURF programs at NIST. The programs are partnerships between NIST and the National Science Foundation (NSF) to provide research opportunities to competitive undergraduate students from under-represented groups with internationally known NIST scientists. The EEEL SURF program is designed to provide hands-on research experience in electrotechnology. Research fields include: fundamental electrical measurements; national electrical standards; electric power systems; flat panel displays; electronic data exchange; compound semiconductor manufacturing; scanning-probe microscopy; thin-film process; simulation and computer-aided design; micro-electro-mechanical systems (MEMS); nanometric linewidth and overlay standards; dielectric and interconnect reliability; law enforcement standards, and forensic Sciences. Further information about the program and application procedures can be found on the website: http://www.eeel.nist.gov/surf.

During the summer of 2002, the EEEL SURF program sponsored 12 students from 8 schools from as far away as California and Puerto Rico. During the final week, presentations were giving where the students summarized their research. Students and projects presented within the Electricity Division were:


2002 Students

Kris Vaughan from University of California, Irving, implemented a vertical active vibration isolation system directly at the knife-edge of the watt balance for the NIST Electronic Kilogram project.

Paul Fleming from State University of New York, Binghamton fabricated a silicon-based single electron tunneling transistor.

Tam Duong from University of California, Irvine, implemented the NIST Check Standard Database, which provides a research tool for the study of long-term behavior of reference standards.

Jonathan Mulholland from St. Mary's College of Maryland characterized an atomic force microscope cantilever using an electrostatic force balance as a link to the SI unit of force.

Reza Hosseinzadeh from Renssaeler Polytechnic Institute developed a control system that regulates the air temperature in the three-story-tall non-magnetic building where the NIST watt balance resides.

NIST's Gaithersburg, Maryland Campus and Surrounding Area

The National Institute of Standards and Technology (NIST) is an agency of the U.S. Department of Commerce's Technology Administration. NIST was established in 1901 by Congress "to assist industry in the development of technology ... needed to improve product quality, to modernize manufacturing processes, to ensure product reliability ... and to facilitate rapid commercialization ... of products based on new scientific discoveries."

Location

Located approximately 40 km Northwest of Washington, D.C., on a 234-hectare campus, NIST Gaithersburg offers the advantages of being in close proximity to government offices, while maintaining the seclusion of a rural setting. The site is beautifully landscaped and features mature trees and ponds, as well as a herd of white-tailed deer and gaggles of Canada geese. Walking paths and picnic areas provide easy and pleasant access for outdoor repasts, biking, walking, and jogging. The campus also is easily accessible, with a shuttle service to a nearby metro (subway) station and is in close proximity to three major airports.

NIST's 11-story Administration Building.

The NIST Gaithersburg, Maryland campus is home to many different types of wildlife.

Staff

NIST's staff consists of about 3,300 scientists, engineers, technicians, business specialists, and administrative personnel. About 1,500 visiting researchers complement the staff. In addition, NIST partners with 2,000 manufacturing specialists and staff at affiliated centers around the country.

Some Nearby Attractions

Landmarks

Capitol Building
Ford's Theater
Franklin Delano Roosevelt Memorial
I.R.S. Building
J. Edgar Hoover F.B.I. Building
Jefferson Memorial
Library of Congress
Lincoln Memorial
National Archives
Supreme Court
Union Station
Vietnam Veterans Memorial
Washington Monument
White House

Museums and Other Attractions

Capital Children's Museum
Corcoran Gallery
Kennedy Center
MCI Center
National Geographic Society
National Sports Gallery
National Theater
Smithsonian Institute
United States Holocaust Memorial Museum
Washington D.C. Convention Center
Wolf Trap Farm Park for the Performing Arts

Outdoor Attractions

C&O Canal National Historical Park
Clara Barton National Historic Site
Eisenhower National Historic Site
Fort McHenry
Fort Washington
Gettysburg National Military Park
Glen Echo Park
Great Falls Park
Greenbelt Park
Mount Vernon
Oxon Hill Farm
Prince William Forest Park
Rock Creek Park
Shenandoah National Park

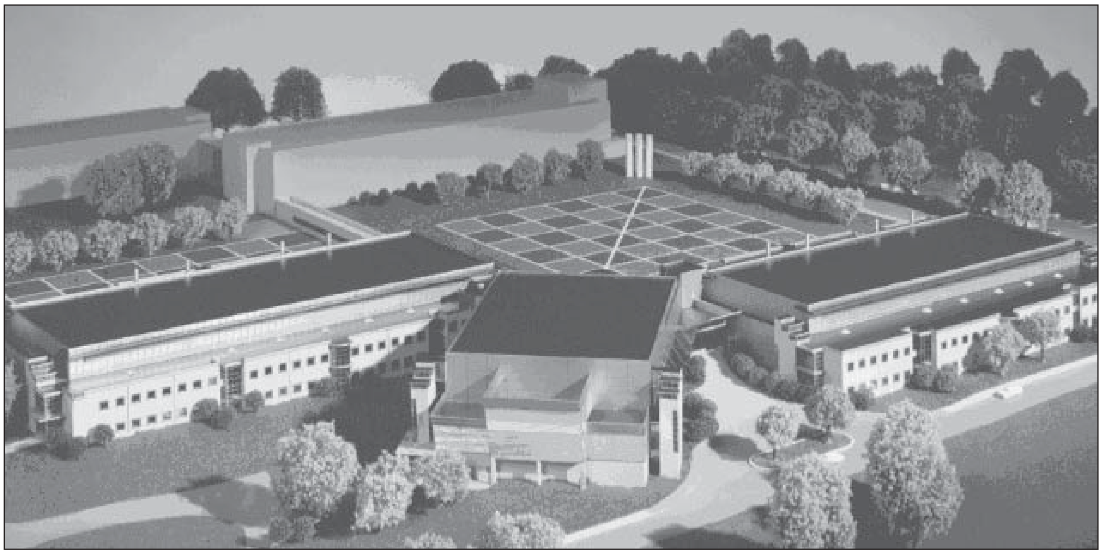
NIST Advanced Measurement Laboratory

The new Advanced Measurement Laboratory (AML) is being constructed on the NIST campus in Gaithersburg, MD. Completion is scheduled for late 2003, with occupancy beginning in 2004. The AML will consist of nearly 50,000 square meters of world-class laboratory space, including a Class 100 cleanroom, 48 precision temperature control lab modules, and 27 low vibration lab modules. Nearly half of the laboratory modules are located in two underground buildings designed for improved temperature and vibration control.

Some of the Electricity Division's research programs will be moving into the underground metrology laboratories. Projects currently scheduled for moving into the AML include the electronic kilogram project, the single electron tunneling project, the calculable capacitor, the DC voltage laboratory, the quantum Hall resistance lab, the power and energy lab, and the fast pulse measurement project.

"The AML is the world-class facility that will provide the United States with global leadership in measurements and standards, and set the foundation for technological advances well into the 21st century … What will come from within these walls will enhance U.S. industrial competitiveness, foster economic growth and improve the quality of life for all Americans."

William Dailey
former Commerce Secretary



AML model showing the Cleanroom (foreground), Instrument East Wing (right), Instrument West Wing (left), and the two underground Metrology Labs (under the hatched areas).

Construction of the AML Cleanroom, late October 2002.

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